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BNGS A MAINTENANCE COOLING PIPING VIBRATION

Report No 90-124-K

H.L. Anderson
Associate Research Engineer
Plant Equipment Dynamics Section
Mechanical Research Department

ABSTRACT

Vibration measurements were performed on the maintenance cooling piping system at Bruce NGS A to provide information to aid in the resolution of vibration related piping system hanger failures. The results of the vibration monitoring that was carried out on Units 2 and 4 maintenance cooling piping during Unit outages are documented in the report. Recommendations for alleviation of the vibration problems are made based on the vibration data.

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EXECUTIVE SUMMARY

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Vibration measurements were performed on the maintenance cooling piping system at Bruce NGS A to investigate vibration related hanger failures on the system. Vibration measurements were performed on Units 2 and 4 during Unit outages in the first quarter of 1990.

Cavitation and high vibration levels were detected in the piping downstream of the orifice in the return line to the reactor. The high vibration and cavitation persisted from the orifice downstream to the penetration to the vault. Of particular concern were high vibrations on the 3/4 inch nitrogen addition lines that are attached to the maintenance cooling piping just upstream of the penetration to the vault. The high vibration has been attributed to flow excitation from the orifice.

Reduction of the high vibration levels on the piping at source by changing the design of the flow control device, the orifice, has been recommended. The recommendation was made based on past experience with a similar problem on the Pickering NGS B moderator piping.

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TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1
2.0	HISTORY OF VIBRATION PROBLEMS ON THE MAINTENANCE COOLING SYSTEM	1
3.0	MEASUREMENT PROCEDURE AND CONDITIONS	2
3.1	System Vibration Survey: January 4, 1990	2
3.2	Unit 2 MCS Vibration Measurements: January 17, 1990	3
3.3	Unit 2 and Unit 4 MCS Vibration: March 20-22, 1990	3
4.0	RESULTS AND DISCUSSION	
4.1	Survey of Service Water Piping: January 4, 1990	3
4.2	Unit 2 MCS Vibration Measurements: January 17, 1990	4
4.3	Unit 2 & 4 MCS Vibration and Flow Measurements: March 20-22, 1990	6
4.3.1	Flow Measurements	6
4.3.2	High Frequency Vibration Measurements	6
5.0	CONCLUSIONS	7
6.0	RECOMMENDATIONS	7
7.0	ACKNOWLEDGEMENTS	8
REFERENCES		9
FIGURES 1 -67		10
DISTRIBUTION		Last Page

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To Mr. P.L. Bourne
Technical Superintendent, BNGS A
Bruce NGS A Operations

BNGS A MAINTENANCE COOLING PIPING VIBRATION

1.0 INTRODUCTION

Vibration measurements were requested for the maintenance cooling piping at Bruce NGS A to provide information to Bruce Engineering to aid in the resolution of vibration-related problems on the system/1/. The maintenance cooling system provides cooling for the reactor during outages in which depressurization of the heat transport system is required. The maintenance cooling system consists of two pumps and a heat exchanger connected between the outlet and inlet headers of the reactor. The primary (D_2O) side of the system operates at approximately 1.4 MPa on the tubeside of the exchanger with service water on the shellside. The system operates under both one and two pump conditions dependent upon the cooling demand.

The layout of the maintenance cooling piping, from the penetration to the reactor building to the pumps, is shown in Figure 1. The majority of the piping is outside containment; however, the control valves MV1 through MV6, lie just inside the reactor building. Lines L1 and L2 carry the hot D_2O from the reactor outlet headers through the pump(s) to the heat exchanger. Lines L9 and L10 carry the cooled D_2O back to the reactor inlet headers. The layout of maintenance cooling piping from the pumps to the heat exchanger and layout of the service water piping in the vicinity of the heat exchangers are shown schematically in Figure 2. Detailed sectional drawings of the maintenance cooling piping are contained in Figures 3, 4, and 5.

2.0 HISTORY OF VIBRATION PROBLEMS ON THE MAINTENANCE COOLING SYSTEM

The events which have triggered the request for vibration monitoring are documented below/2/.

(A) In Unit 1 hangers HR17, HR18, HR47 and HR48 on maintenance cooling lines L1, L2, L10 and L9 respectively, located just outside the reactor building, were found to have loosened to the point where they fell apart. Damage to these hangers was also noted in the March 1990 Unit 4 outage.

(B) Subsequent to (A) on Unit 1 hangers HS45 on L9, HS46 on L10, and HV20 on L1 were found to have broken away from the wall attachments. These hangers are located approximately 3m from the damage in (A).

HS46, which was then hanging on L10, had worn a groove into the line approximately 20% through the wall.

(C) In Unit 2 Hanger HS44 on L9 on the horizontal run just downstream of the orifice and the Tee was found to be wearing into the line.

(D) In Unit 4 hanger HS36 on the primary inlet nozzle to the heat exchanger was found to be deformed as though the heat exchanger had lifted off the floor.

(E) Some heat exchanger floor anchors were found to be broken and grout in the area of the broken floor anchors was cracked.

(F) Support HS28 on the inlet to pump P1 was lifted in one Unit approximately 2.5 cm above its support plate.

3.0 MEASUREMENT PROCEDURE AND CONDITIONS

Vibration measurements were taken on the maintenance cooling piping on Unit 2 on January 4, January 17, and March 22, 1990 during the maintenance outage. The measurements were taken under one and two pump conditions. The maintenance cooling system conditions for the measurements on Unit 2 are documented in Tables 1 through 3. The locations for the vibration measurements are shown in Figures 2 through 5.

Vibration measurements were made on the Unit 4 maintenance cooling piping under one and two pump operation in its outage on March 20, 1990. The maintenance cooling system conditions for the measurements on Unit 4 are documented in Table 4.

Flow measurements were taken under one and two pump operating conditions in Units 2 and 4 on March 22, 1990. The location for the flow measurements is indicated in Figure 1. The flows were measured with a non-intrusive ultrasonic flowmeter, Controlotron System 990 Transit Time Flowmeter.

3.1 System Vibration Survey: January 4, 1990

The vibration data taken on January 4, 1990 were obtained to survey the maintenance cooling system and the associated service water side in order to identify areas of concern. The data were obtained in acceleration using a magnetically mounted B&K model 4382 accelerometer. The acceleration data were recorded on a SONY digital audio tape(DAT) recorder which has a dynamic range of 85 dB.

The data obtained on January 4 revealed that the major area of concern in the system was the section of piping in the vicinity of the orifice in L10. The vibration levels on the service water piping were quite low. As a result of the January 4 measurements the decision was made to concentrate on the maintenance cooling system (MCS) piping from the penetration to the heat exchanger. Thus, the only data on the service water piping, locations 1 through 6, was obtained on January 4 with the magnetically mounted accelerometer under one pump operation.

3.2 Unit 2 MCS Vibration Measurements: January 17, 1990

Two types of vibration measurements, documented below, were taken on the maintenance cooling piping on January 17.

I. A B&K 4393 accelerometer mounted on B&K studs glued on the piping and heat exchanger was used to monitor the following data:

a) Shell mode vibration of the piping at frequencies in excess of 100 Hz;

b) Acoustic flow phenomena in the piping and the heat exchanger; eg, cavitation, turbulence and acoustic resonances.

The data were recorded in acceleration on the SONY DAT recorder which, because of its excellent dynamic range, permitted later integration of the data if necessary.

II. A B&K triaxial accelerometer, model 4321, was magnetically mounted on the piping to monitor bending mode vibration in three directions at location 22A on L10 just downstream of the orifice, and location 26A on L1, adjacent to the orifice in L10. The bending modes are significant at frequencies less than 100 Hz. Low frequency motion of the pump P1 was monitored on the bowl of the pump. The bending mode vibration was monitored in displacement and recorded on a B&K 7003 tape recorder at 1.5 inches/s, DC coupled.

3.3 Unit 2 and Unit 4 MCS Vibration: March 20-22, 1990

Vibration levels were monitored in Units 2 and 4 under single and two pump operation at locations 21 through 24, on the line containing the orifice. The vibration was monitored using a B&K 4375 accelerometer stud-mounted at each location. The data were recorded on the SONY DAT recorder. The vibration measurements were taken at the same time as the flow measurements were recorded.

4.0 RESULTS AND DISCUSSION

4.1 Survey of Service Water Piping: January 4, 1990

The results of the service water system survey in Unit 2, taken with the magnetically mounted accelerometer, are summarized in Table 5. The spectra of the service water system vibration data are presented in Figures 6 through 12. The mounted resonance of the magnet mounted accelerometer ranged from 4500 - 8200 Hz, depending on pipe size(flatness of surface). The service water measurements were only taken in the Jan. 4 survey and are presented for completeness.

The data obtained on January 4 for the maintenance cooling system piping is not presented as the measurements were repeated on January 17 and March 22. The data obtained with stud-mounted accelerometers on the latter two dates are considered more accurate than the magnetically mounted accelerometer data: the mounted resonance of the stud-mounted accelerometer is high enough that it will not artificially amplify the vibration levels extant in the system.

The vibration levels measured on the service water piping were too low, < 3 ms^{-2} rms, to be responsible for the damage observed on the grouting and hangers in the vicinity of the heat exchangers.

4.2 Unit 2 MCS Vibration Measurements: January 17, 1990

The results of the monitoring on the Unit 2 maintenance cooling piping system taken under two pump operation on January 17, 1990 are summarized in Table 6 which documents the overall rms acceleration levels measured at each location. Spectra of the rms acceleration levels measured at each location are contained in Figures 13 to 31.

The acceleration levels in the vicinity of the pumps and the heat exchanger, locations 7 through 17, were all less than 30ms^{-2} rms overall, as documented in Table 6 and Figures 13 to 20.

The highest acceleration levels were detected on the piping that carries the cooled D_2O flow from the heat exchanger to the reactor inlet header, L10 and L9. The regions of highest vibration on these lines were located in the vicinity of the orifice on L10 and just upstream of the penetration to the vault on L9 and L10.

The two highest acceleration levels measured on the main piping were detected on L9 at locations 23 and 30. The pipe L9 is the direct extension of the piping downstream of the orifice. The response spectrum at location 23, a few feet downstream of the orifice on L9, is contained in Figure 23. The overall rms acceleration level at location 23 was 78.4 ms^{-2}, comprising a narrow peak at approximately 3800 Hz and a broad band response from 2kHz to 10kHz at a level of about 7 ms^{-2} rms. Sounds of cavitation were detected by audio monitoring of the acceleration signal. The broad band response is due to flow turbulence and cavitation. The broad band response is not present in spectra upstream of the orifice; for example, at location 21 just upstream of the orifice there is no evidence of broad band response in the spectrum in Figure 21 and the overall rms acceleration level measured there was 35.5 ms^{-2}, half that at location 23.

The high frequency excitation from the orifice was not transmitted to line L10 which branched off the line immediately downstream of the orifice. The vibration level measured on L10 just downstream of the "Tee" at location 22 was only 41.8 ms^{-2} rms overall with no evidence of broad band excitation as shown in Figure 22.

At location 30 in the vicinity of HR48 on L9, just upstream of the penetration, an overall rms acceleration level of 78.5 ms^{-2} was measured, approximately equivalent to the levels measured on L9 at location 23. The response spectrum, contained in Figure 29, was made up of a narrow

peak of 16 ms^{-2} rms at 800 Hz and broad band excitation at approximately 7 ms^{-2} rms over the range from 2kHz to 10kHz. The narrow peak at 800 Hz is most likely a shell mode of the pipe. The broad band excitation, which is almost identical to that measured at location 23, is most likely due to flow noise generated at the orifice through cavitation and turbulence. Some cavitation could be detected in audio monitoring of the signal from location 30. From experience on the Pickering Moderator piping it is known that cavitation and turbulent excitation can persist far downstream of the orifice/3,4/.

The high frequency response of L10 at location 29, adjacent to L9 and location 30 near the penetration, is shown in Figure 28. The overall rms level measured at location 29 was 34.4 ms^{-2} rms, approximately half that at location 30, composed of a narrow peak of 13 ms^{-2} rms at 800 Hz similar to L9 but **without the broad band excitation** found on L9.

Of greatest concern in the evaluation was the response of the 3/4 inch nitrogen addition line at Location 32 attached to L9 just upstream of the penetration to the vault. The high frequency excitation from the orifice was transmitted through the wall of the line to the attached 3/4 inch line whose response is documented in Tables 6 and 7 and in Figures 31 through 34. The overall rms acceleration level up to 20 kHz at location 32 was 114 ms^{-2}. In order to look in more detail at frequencies below 1 kHz, the data was integrated to velocity as shown in the spectrum in Figure 31. The dominant rms velocity response was 32.4 mm/s rms at 105 Hz, equivalent to an rms acceleration of 21.4 ms^{-2} rms. Assuming a pipe schedule of 80, the response at location 32 represents a normalized acceleration value, a_n, of 0.75 which exceeds the allowable vibration limit of a_n of approximately 0.4 at 105 Hz/5/. The peak-to-peak north-south displacement of the line was 0.7mm.

While the high frequency flow noise in Unit 2 did not travel through L10 from the orifice, it appeared that the low frequency bending mode response of the two lines downstream of the orifice was similar, ie the piping appeared to move in unison. The response of L10 at location 22A downstream of the orifice is documented in Figures 35 to 40 and Table 7. The maximum peak-to-peak displacement of L10 at location 22A was 5.0 mm in the north-south direction, with levels of 2.3 mm and 1.1 mm in the east-west and vertical directions respectively. The dominant response of the line was at 4.45 Hz at a level of 0.52 mm rms in the north-south direction **which is above the allowable displacement permitted for Group 2 piping in reference 5.** It is expected that the low frequency response of L9 just downstream of the orifice would be at least as high as that measured at location 22A on L10.

The bending mode response of one of the lines from the outlet headers was measured at location 26A on L1, beside 22A on L10. The data from location 26A are documented in Table 7 and Figures 41 to 46. The maximum response was 2.0 mm peak-to-peak in the vertical direction with 1.5 mm and 0.7 mm peak-to-peak in the north-south and east-west directions respectively. The modes of response were at 2.7 Hz, 3.8 Hz, 4.5 Hz and 5.3 Hz. Comparison of the rms spectra for locations 22A and 26A reveal that the dominant bending mode response was on the lines carrying the cooled D_2O to the inlet headers, ie those attached to the orifice line. The response of L1 was below the allowable for 12 inch, schedule 100 piping (Group 2)/5/.

The low frequency motion on the Pump 1 is documented in Table 7 and in Figures 47 to 52. The responses at the pump bowl were 1.3 mm, 1.1 mm, and 1.4 mm peak-to-peak in the north-south, east-west and vertical directions respectively. The spectra from the pump show the response to be similar that of L1 at location 26A.

4.3 Units 2 & 4 MCS Vibration and Flow Measurements: March 20-22/90

The goals of the March 20 and 22 measurements are outlined below.

(A) Measure flow rates through the MCS under one and two pump operation;

(B) Determine whether similar vibration conditions exist in both Units.

4.3.1 Flow Measurements

Flow measurements were taken on L1 on the long straight horizontal run upstream of the pumps as shown in Figure 1. The flow rates measured in Units 2 and 4 are documented below.

No. of Pumps	Flow Rate(L/s)
1	316 to 320
2	378 to 382

For L10 just upstream of the orifice, the Reynolds' numbers for the flow conditions at the time of measurement are $1.8*10^6$ and $2.1*10^6$ for one and two pumps respectively. The flows in this Reynolds' number range are highly turbulent. The moderator flow at Pickering B which had persistent cavitation far downstream of the orifice had a Reynolds' number of $4*10^6$, the same regime present in the MCS.

4.3.2 High Frequency Vibration Measurements

The vibration measurements were concentrated in the vicinity of the orifice. The data are contained in Table 8 and Figures 53 to 67. The Unit 2 data reveal the same pattern of vibration response measured on Unit 2 during the two-pump operation of January 17. The new data from March are the measurements at location 24 which was immediately downstream of the orifice before the flow-splitting Tee.

The vibration levels for Unit 4 were 20% to 30% higher than those measured on Unit 2 for similar operating conditions. One significant difference between Unit 2 and Unit 4 is in the measurements from location 22 on L10 downstream of the Tee: In Unit 2 under two pump operation no broad band response was observed on L10 at location 22, Figure 58; however, in Unit 4 under two pump operation a significant broad band high frequency response was observed at location 22, Figure 65, at an overall rms level twice as high as that on Unit 2. The overall vibration level at location 23 on L9 was 34% higher than the levels at location 22 in Unit 4 for the two pump conditions.

While no high frequency measurements were taken on Unit 4 near the hangers it is reasonable to expect a similar increase in vibration levels as measured in Unit 2. The same expectation holds for low frequency measurements on the main lines just downstream of the orifice.

5.0 CONCLUSIONS

5.1 Cavitation and high vibration levels have been detected in the piping downstream of the orifice in the maintenance cooling system. The problem persists from the orifice to the penetration to the vault. The high vibration has been attributed to flow excitation from the orifice based on the pattern of vibration observed.

5.2 Low frequency vibration on the main piping exceeded allowable levels at locations just downstream of the orifice/5/. High frequency vibration levels exceeded the allowable on the 3/4" nitrogen addition line attached to L9 near the vault penetration.

5.3 The high frequency excitation is the most likely cause of most of the hanger problems on the MCS piping.

5.4 The vibration levels on the pumps, heat exchangers and associated piping were too low to be responsible for the damage observed in the heat exchanger grout and supports in the vicinity. It is most likely that the damage observed is due to problems with water hammer on the secondary side (service water) of the system in the early days of operation/2/.

6.0 RECOMMENDATIONS

6.1 Vibration levels should be reduced on the maintenance cooling piping downstream of the orifice.

6.2 Damage from the low frequency vibration observed may be alleviated by addition of, or changes to, the piping supports; however, changes to the supports on the main piping will not change the high levels observed on the 3/4 inch nitrogen addition line. Thus, it is recommended that the problem be attacked at the source by changing the design of the orifice to a flow restricting device that would yield the same flow control while reducing the cavitation and large scale turbulence.(A similar solution was successfully applied to the Pickering NGS B moderator piping system/3,4/.)

7.0 ACKNOWLEDGEMENTS

The vibration measurements and data reduction were performed by M. DeMontmorency. The flow measurements were taken by R. Black. Their contribution to this program is gratefully acknowledged. The assistance of the Bruce A Operations staff, particularly Ed Nowakowski, is greatly appreciated.

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5. M. Mikasinovic, J.M. Czarnogorski, "Vibration Monitoring Procedure for Piping Systems of Darlington NGS A", Revision 2, May 1987.

TABLE 1

UNIT 2

JANUARY 4, 1990 SYSTEM CONDITIONS for VIBRATION MEASUREMENTS

SYSTEM PARAMETER	2 MTCE COOLING PUMPS IN OPERATION	ONE MTCE COOLING PUMP IN OPERATION
PHT: -temp -level - pressure	N/A	30°C ≈1m depressurized
MTCE Cooling Pump: P1 P2	N/A	 on off
VALVE POSITION: 3472-MV1 3472-MV2 3472-MV4 3472-MV5 3472-MV3 3472-MV6	N/A	 open open open throttled closed closed
Service Water control valve position: 7131-TCV23	N/A	 10% open
MTCE cooling Temp.: 3472-TT5 3472-TT11	N/A	 29.5°C 29.5°C
MTCE clg Pressure: 3472-PT6 3472-PT5	N/A	 0.99 MPa 0.22 MPa
Purification Flow: Position MV15 Position MV16	N/A	7.72 kg/s throttled open

TABLE 2

UNIT 2

JANUARY 17, 1990 SYSTEM CONDITIONS for VIBRATION MEASUREMENTS

SYSTEM PARAMETER	2 MTCE COOLING PUMPS IN OPERATION	ONE MTCE COOLING PUMP IN OPERATION
PHT: -temp -level - pressure	30°C ≈1m 160 kPa	N/A
MTCE Cooling Pump: P1 P2	 ON ON	
VALVE POSITION: 3472-MV1 3472-MV2 3472-MV4 3472-MV5 3472-MV3 3472-MV6	 open open open open closed closed	N/A
Service Water control valve position: 7131-TCV23	 10% open	N/A
MTCE cooling Temp.: 3472-TT5 3472-TT11	 30°C 30°C	N/A
MTCE clg Pressure: 3472-PT6 3472-PT5	 1.29 MPa 0.21 MPa	N/A
Purification Flow: Position MV15 Position MV16	9.1 kg/s open open	N/A

TABLE 3

UNIT 2

MARCH 22, 1990 SYSTEM CONDITIONS for VIBRATION MEASUREMENTS

SYSTEM PARAMETER	2 MTCE COOLING PUMPS IN OPERATION	ONE MTCE COOLING PUMP IN OPERATION
PHT: -temp -level - pressure	30° ≈4 m 50 - 100 kPa	30°C ≈4m 50 - 100 kPa
MTCE Cooling Pump: P1 P2	 ON ON	 OFF ON
VALVE POSITION: 3472-MV1 3472-MV2 3472-MV4 3472-MV5 3472-MV3 3472-MV6	 open open open throttled closed closed	 open open open throttled closed closed
Service Water control valve position: 7131-TCV23	 10% open	 10% open
MTCE cooling Temp.: 3472-TT5 3472-TT11	 29.5 29.4	 29.5°C 29.4°C
MTCE clg Pressure: 3472-PT6 3472-PT5	 1.35 MPa 0.27 MPa	 1.07 MPa 0.25 MPa
Purification Flow: Position MV15 Position MV16	8.5 kg/s cracked open open	7.2 kg/s cracked open open

TABLE 4

UNIT 4

MARCH 20, 1990 SYSTEM CONDITIONS for VIBRATION MEASUREMENTS

SYSTEM PARAMETER	2 MTCE COOLING PUMPS IN OPERATION	ONE MTCE COOLING PUMP IN OPERATION
PHT: -temp -level - pressure	23.5°C 74.7% 200 kPa	23.5°C 74.7% 200 kPa
MTCE Cooling Pump: P1 P2	 ON ON	 OFF ON
VALVE POSITION: 3472-MV1 3472-MV2 3472-MV4 3472-MV5 3472-MV3 3472-MV6	 open open open throttled closed closed	 open open open throttled closed closed
Service Water control valve position: 7131-TCV23	 20% open	 20% open
MTCE cooling Temp.: 3472-TT5 3472-TT11	 22.7°C 23.6°C	 22.5°C 23.6°C
MTCE clg Pressure: 3472-PT6 3472-PT5	 1.35 MPa 0.23 MPa	 1.04 MPa 0.23 MPa
Purification Flow: Position MV15 Position MV16	3 kg/s open open	3 kg/s open open

TABLE 5

SUMMARY OF SURVEY OF MCS & SERVICE WATER PIPING MAINTENANCE COOLING PUMP P1 ON JANUARY 4, 1990

Location	Vibration Level in ms^{-2} rms overall: 0 to 20 kHz
1, service water(sw) piping	0.4
2, sw piping, upstream of V583	0.62
3, sw inlet nozzle to hx	0.94
4, sw outlet nozzle from hx	0.41
5, sw hx outlet line dnstrm of TCV23	2.06
6, sw 3/4 inch line on hx	2.78
7, shell of hx	1.1

TABLE 6

SUMMARY OF VIBRATION MEASUREMENTS ON MCS PIPING MAINTENANCE COOLING PUMPS P1 & P2 ON JANUARY 17, 1990

Location	Vibration Level in ms^{-2} rms overall: 0 to 20 kHz
7, heat exchanger shell	0.932
12A, L1 u/s of pumps	6.2
12, upstream of P2	15.3
13, upstream of P1	17.8
14, downstream of P1	17
15, downstream of P2	19.6
16, L7 upstream of Tee to line to hx	15.9
17, L10, downstream of hx	29.4
21, L10 just upstream of orifice	35.5
22, L10 d/s of orifice and Tee	41.8
23, L9 d/s of orifice and elbow	78.4
25, L1 d/s of Tee	5.7
26, L1 u/s of Tee	5.2
27, L2 u/s of Tee	6.7
28, L1 near penetration, near HR17	5.5
29, L10 near penetration, near HR47	34.4
30, L9 near penetration, near HR48	78.5
31, L2 near penetration, near HR18	7.4
32, elbow on nitrogen addition line attached to L9 near location 30	114

TABLE 7

SUMMARY OF DISPLACEMENT MEASUREMENTS ON MCS PIPING MAINTENANCE COOLING PUMPS P1 & P2 ON JANUARY 17, 1990

LOCATION	DISPLACEMENT IN mm peak-to -peak
32, elbow on nitrogen addition line attached to L9, north-south direction	0.7
22A, L10 downstream(d/s) of orifice:	
north-south	5.0
east-west	2.3
vertical	1.1
26A, L1 just upstream of Tee:	
north-south	1.5
east-west	0.7
vertical	2.0
13, pump bowl of pump P1:	
north-south	1.3
east-west	1.1
vertical	1.4

TABLE 8

SUMMARY OF ACCELERATION MEASUREMENTS ON MCS PIPING
UNIT 2 AND UNIT 4
ONE & TWO PUMP OPERATION
MARCH 20 AND 22, 1990

LOCATION	No. of pumps in operation	UNIT 2: Vibration Level in ms^{-2} rms overall: 0 to 20 kHz	UNIT 4: Vibration Level in ms^{-2} rms overall: 0 to 20 kHz
21, L10 upstream of orifice	1 2	26.3 36.6	29.4 49.6
24, L10 immediately downstream of orifice	1 2	49.4 79.0	55.4 94.9
22, L10 downstream of orifice and elbow	1 2	35.6 45.9	63.3 88.5
23, L9 downstream of orifice and elbow	1 2	53.9 n/a	71.6 119.0

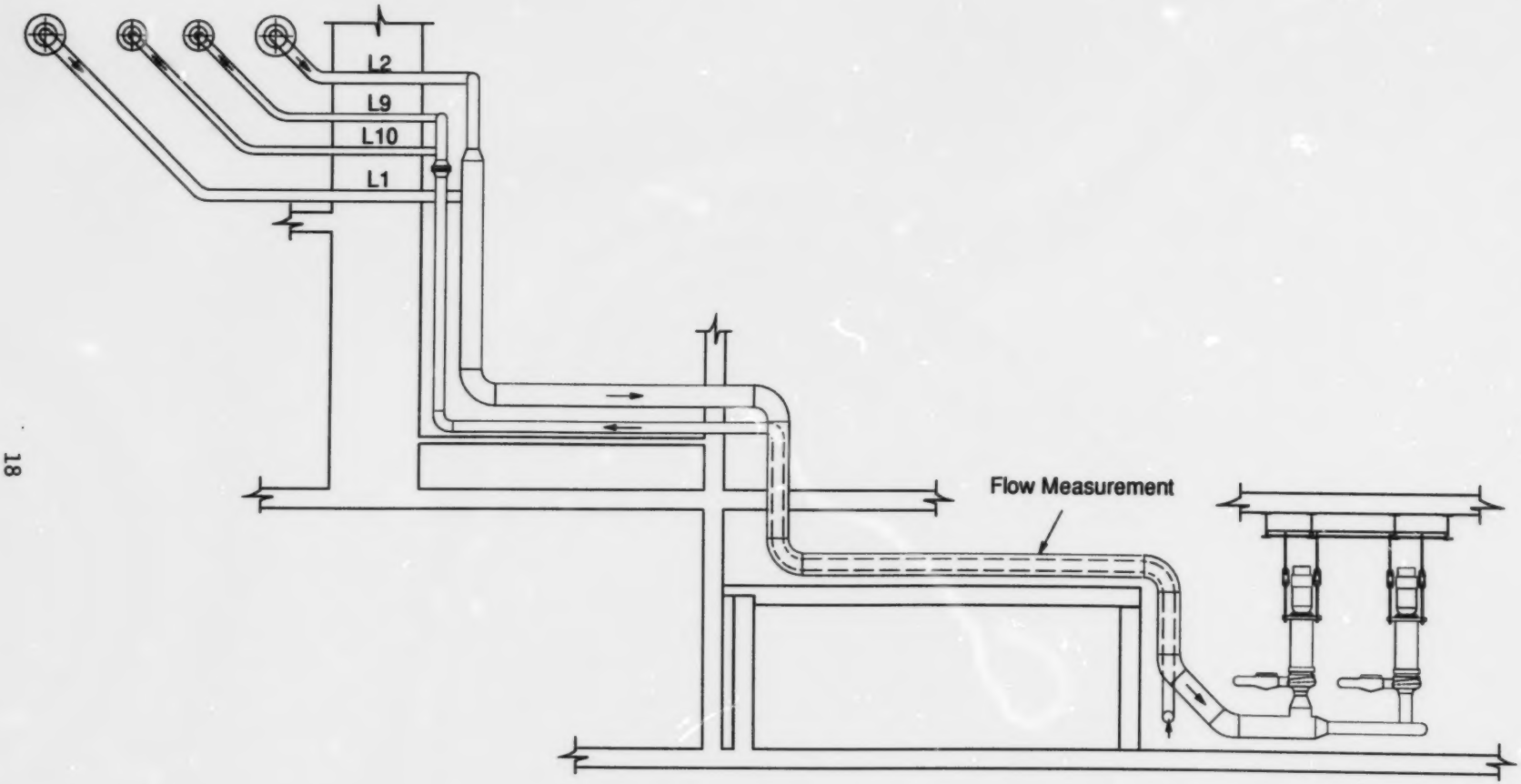


FIGURE 1

MAINTENANCE COOLING SYSTEM PIPING LAYOUT

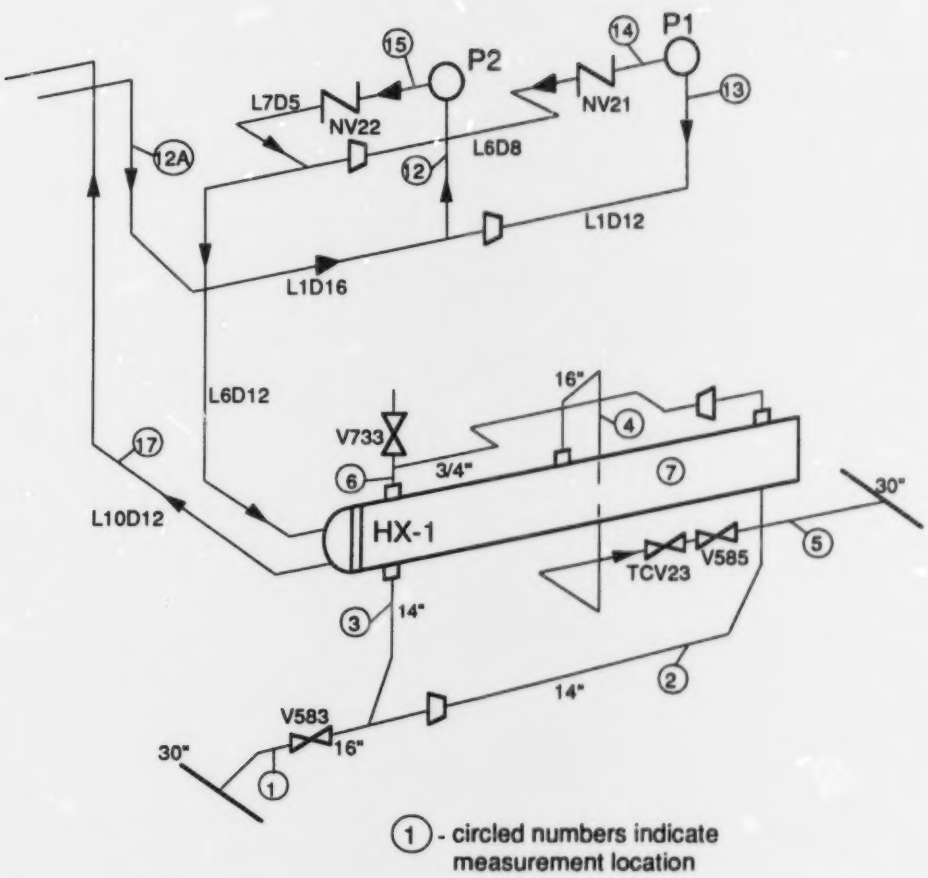


FIGURE 2

SCHEMATIC LAYOUT OF PIPING IN THE VICINITY OF THE MCS PUMPS AND Hx

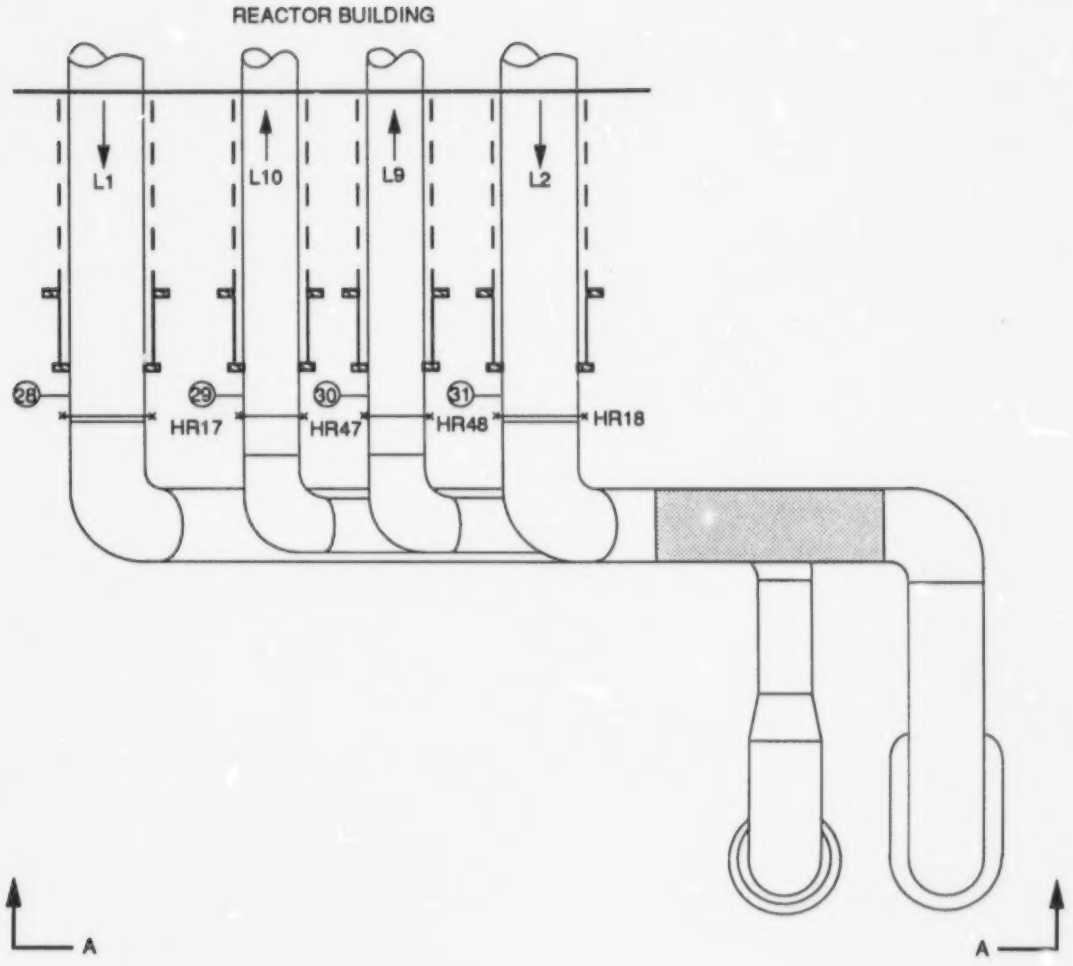


FIGURE 3

PIPING AT PENETRATION TO REACTOR BUILDING

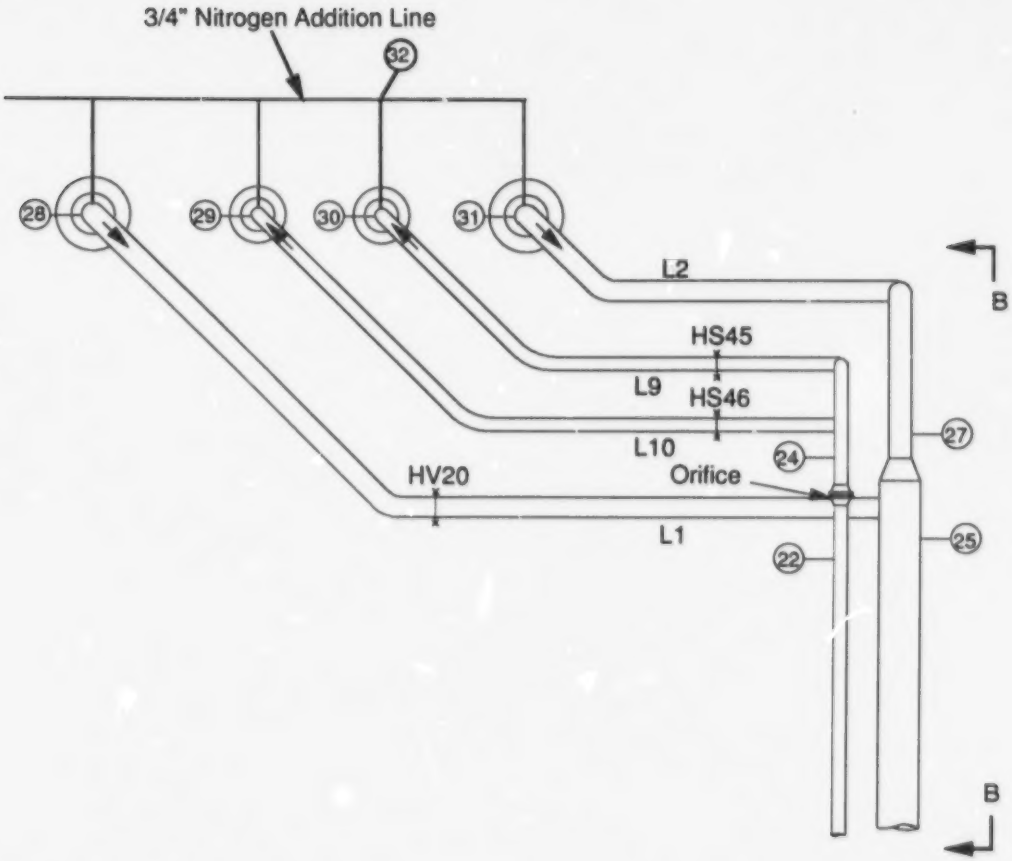


FIGURE 4

VIEW A-A

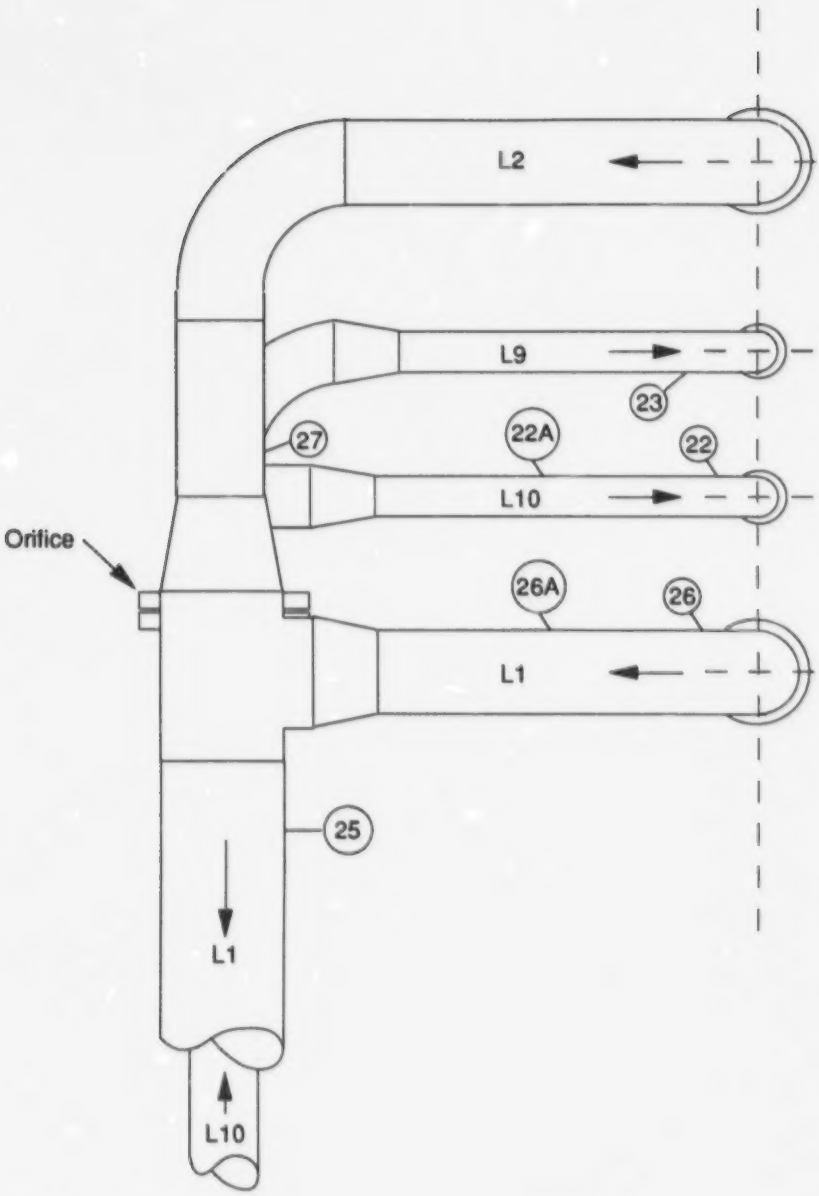
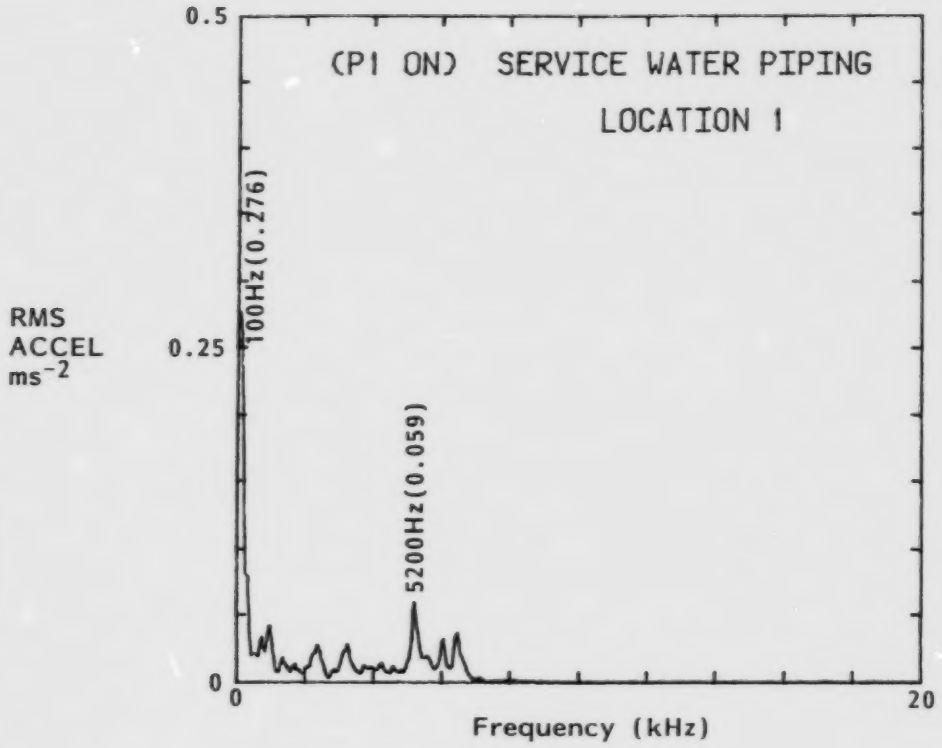


FIGURE 5

VIEW B-B



*Note: Where numbers appear above the spectral peaks the first value above the peak is the frequency; the number in brackets is the amplitude of the peak.

FIGURE 6

BNGS U2 MAINTENANCE COOLING SYSTEM 90.01.04

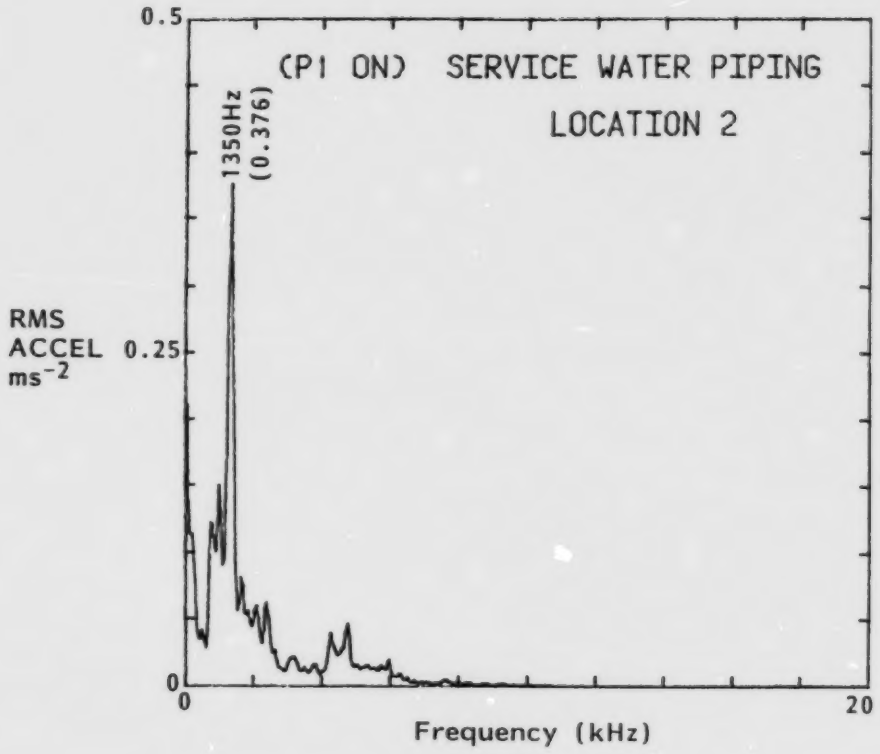


FIGURE 7

BNGS U2 MAINTENANCE COOLING SYSTEM 90.01.04

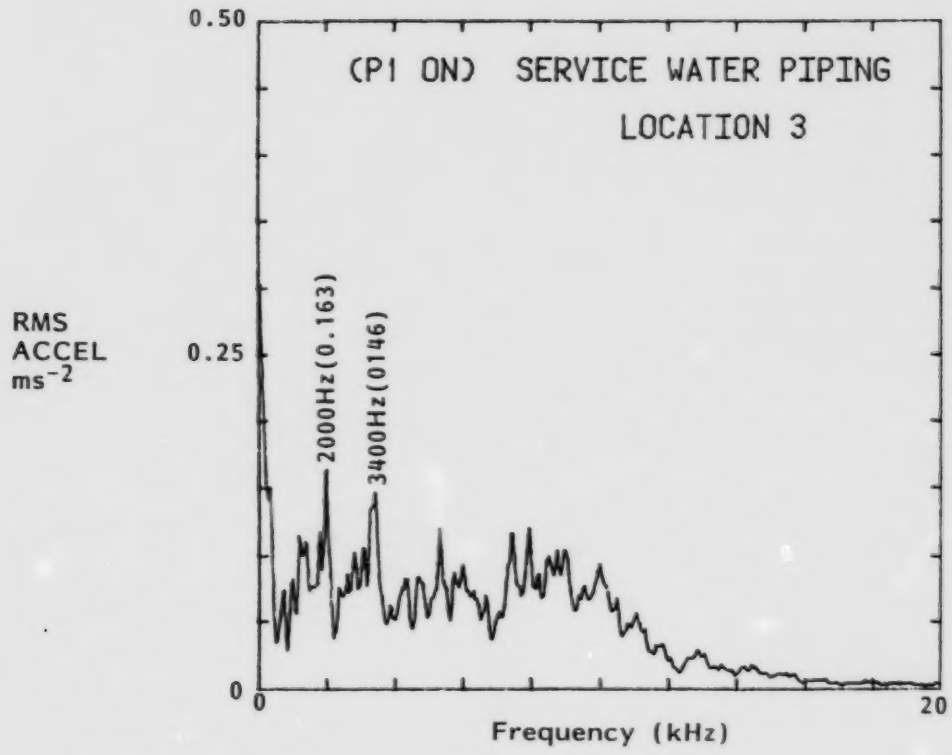


FIGURE 8

BNGS U2 MAINTENANCE COOLING SYSTEM 90.01.04

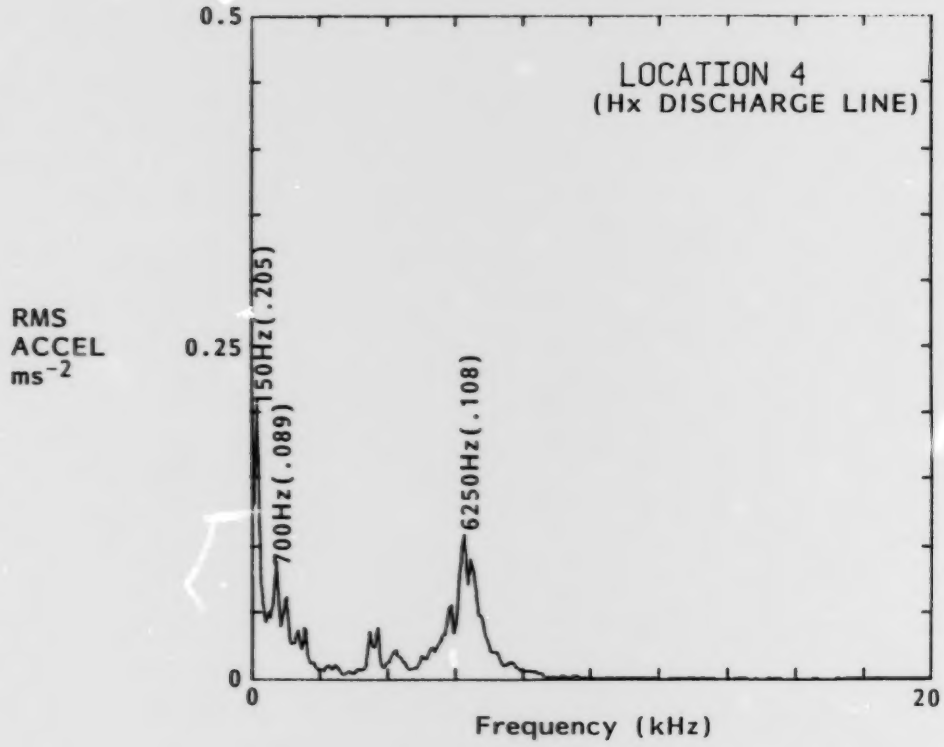


FIGURE 9

BNGS U2 MAINTENANCE COOLING SYSTEM 90.01.04

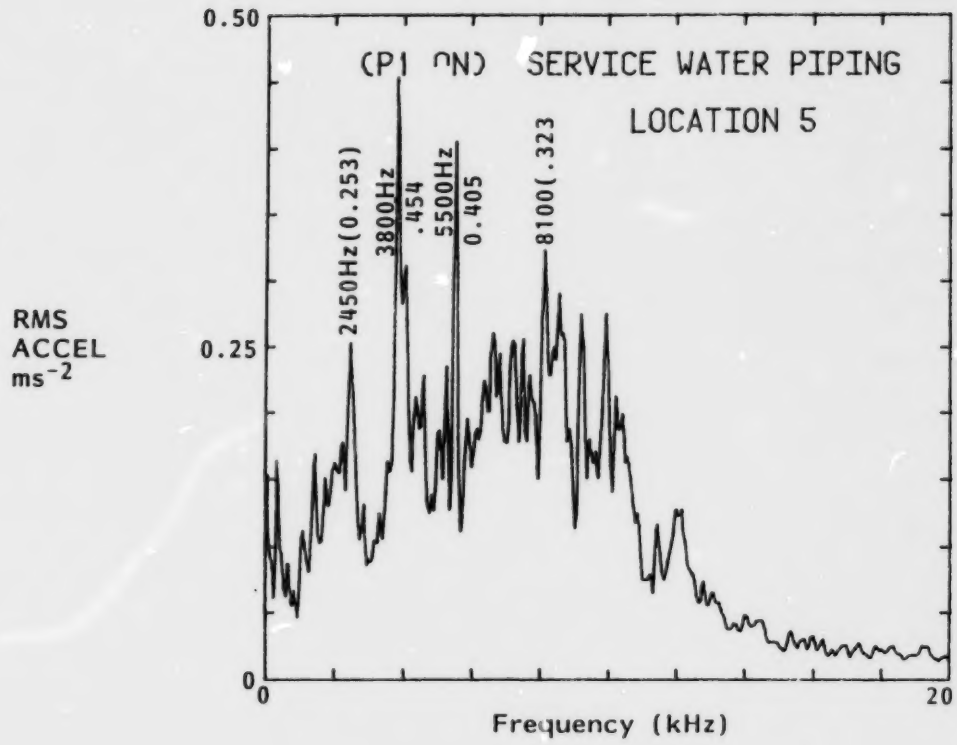


FIGURE 10

BNGS U2 MAINTENANCE COOLING SYSTEM 90.01.04

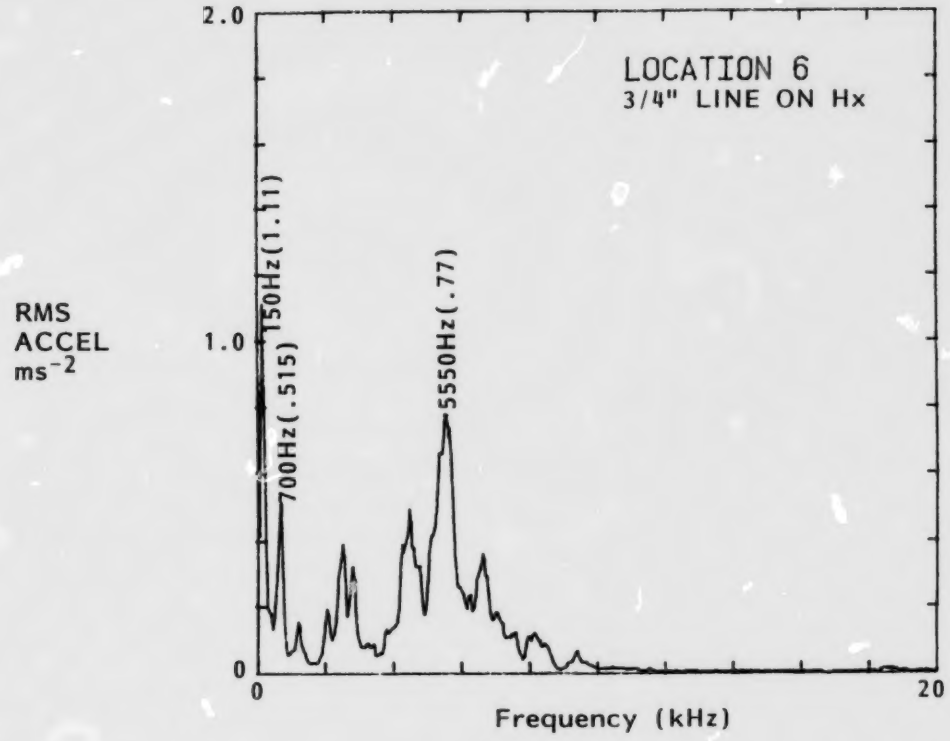


FIGURE 11

BNGS U2 MAINTENANCE COOLING SYSTEM 90.01.04

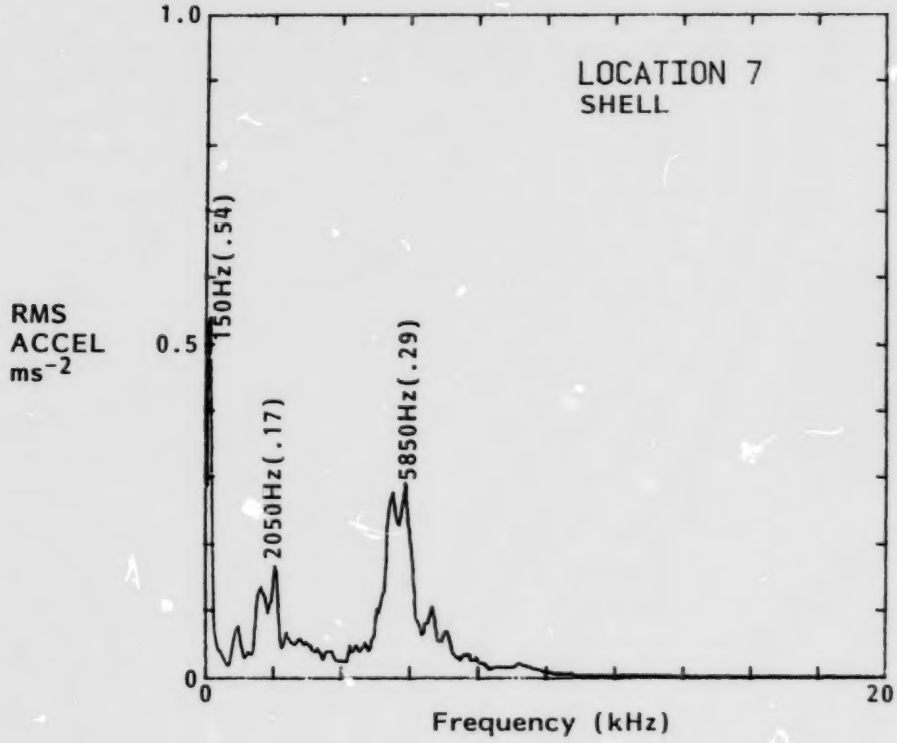


FIGURE 12

BNGS U2 MAINTENANCE COOLING SYSTEM 90.01.04

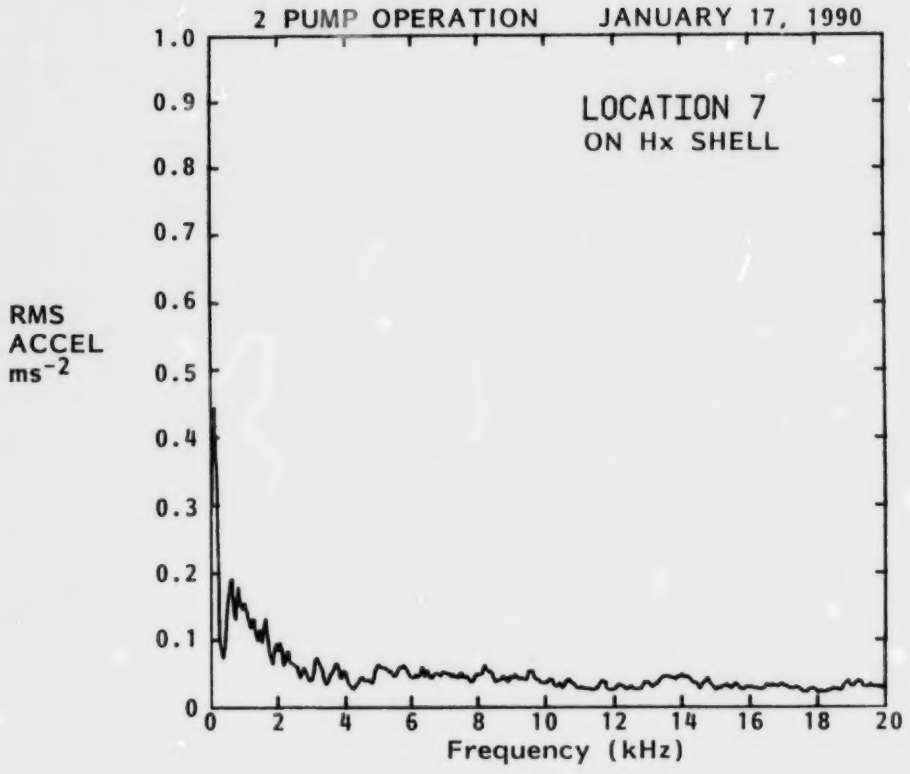


FIGURE 13

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

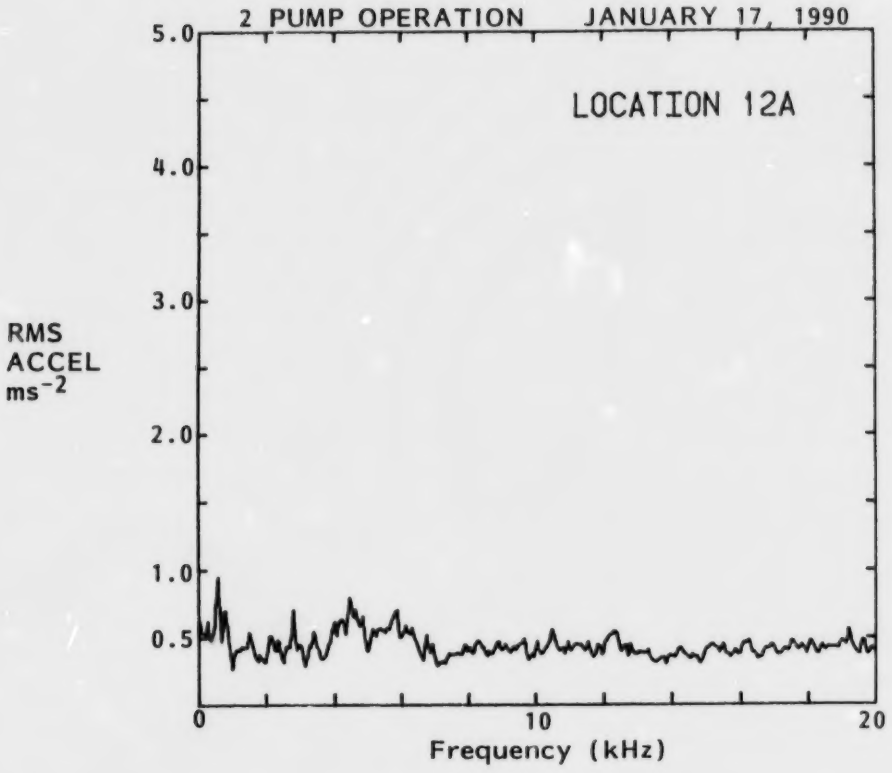


FIGURE 14

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

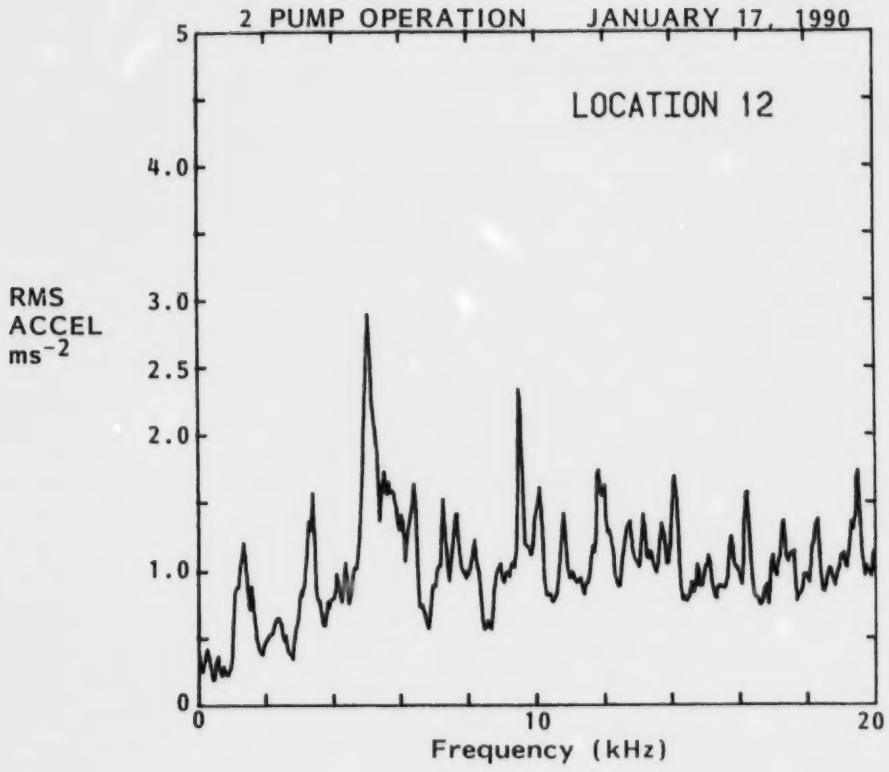


FIGURE 15

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

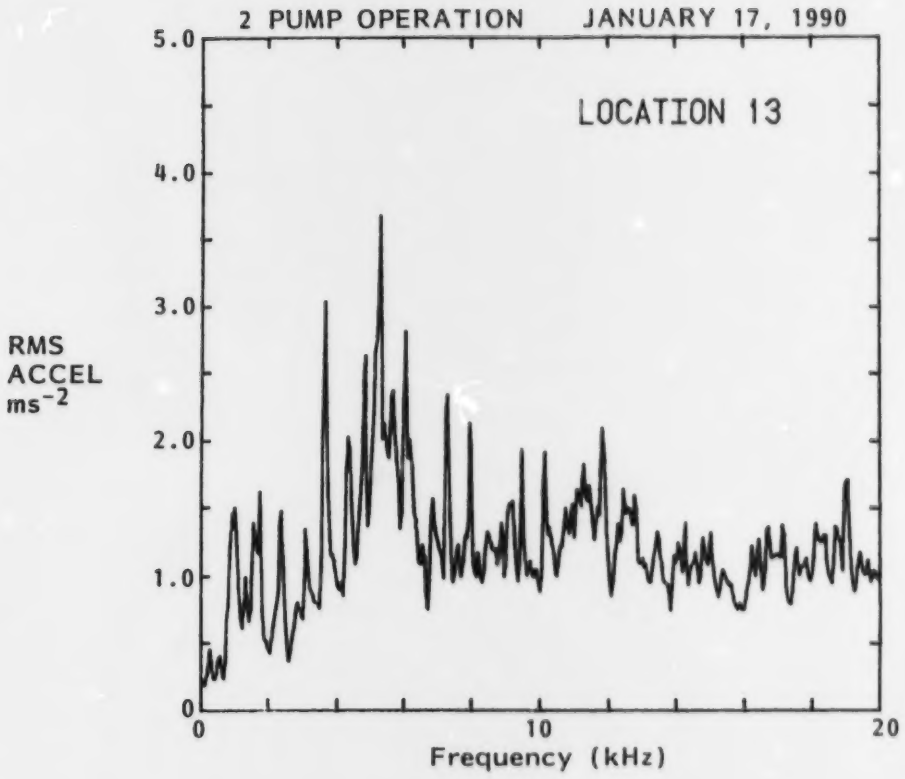


FIGURE 16

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

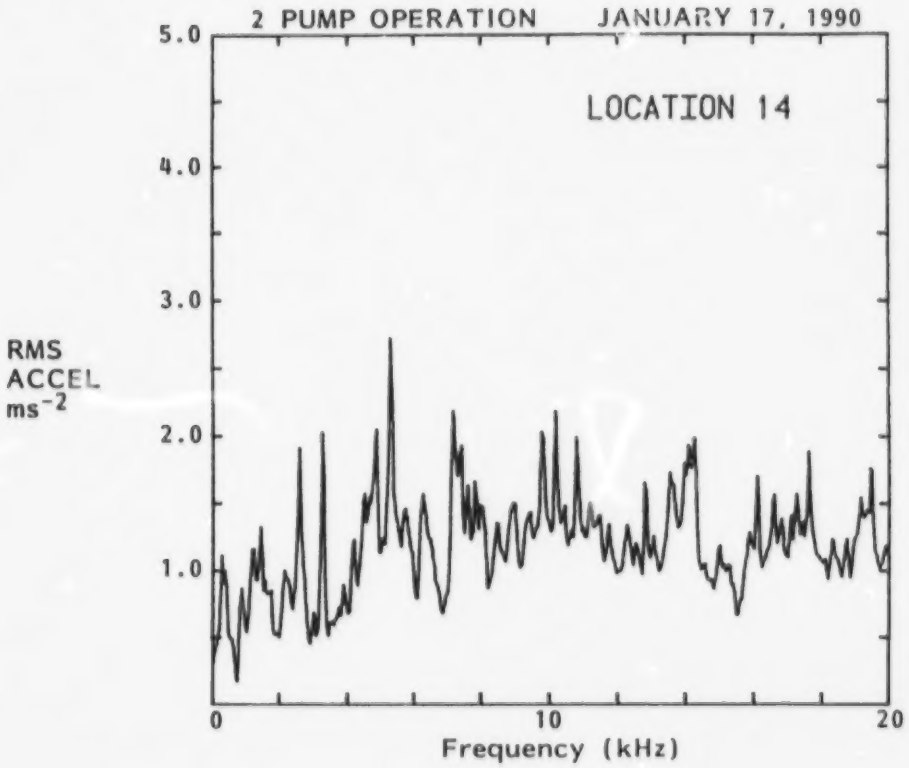


FIGURE 17
BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

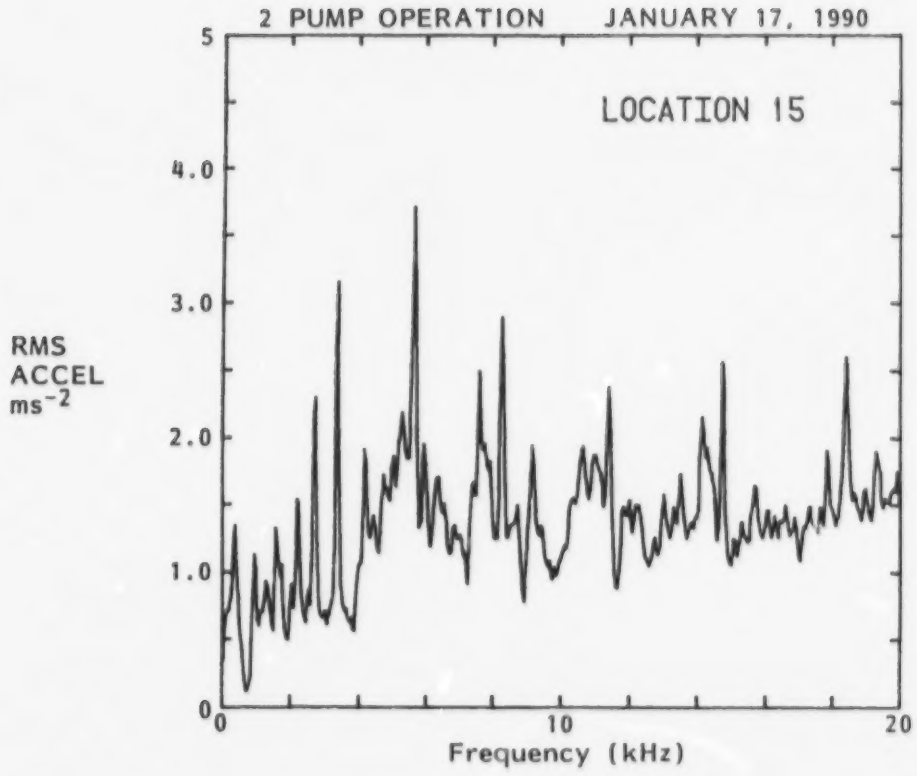


FIGURE 18
BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

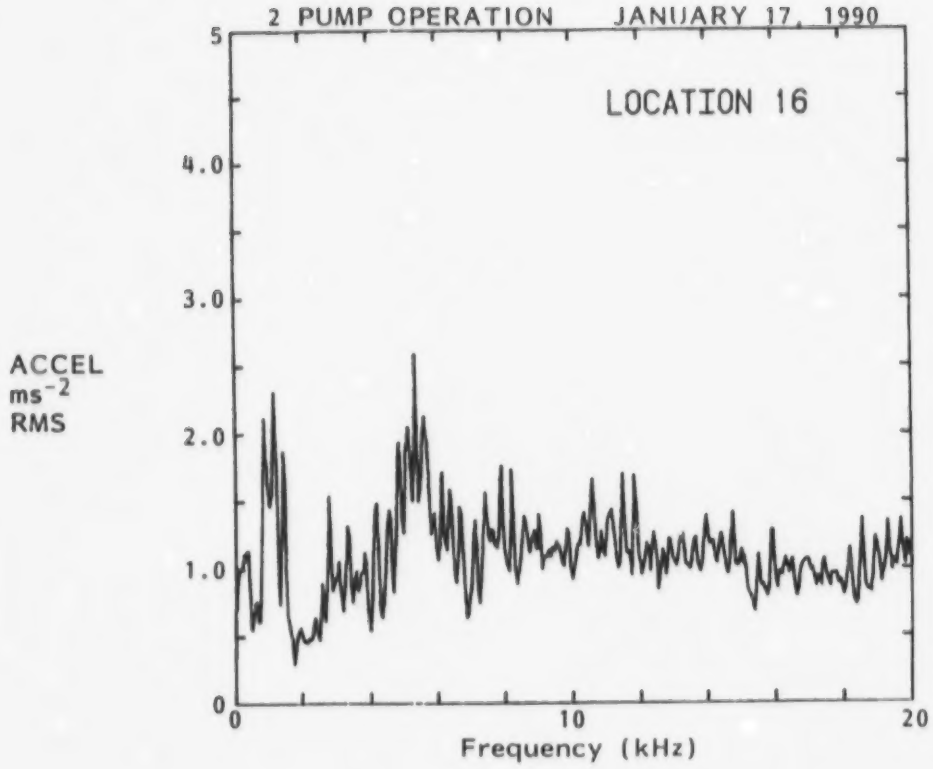


FIGURE 19

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

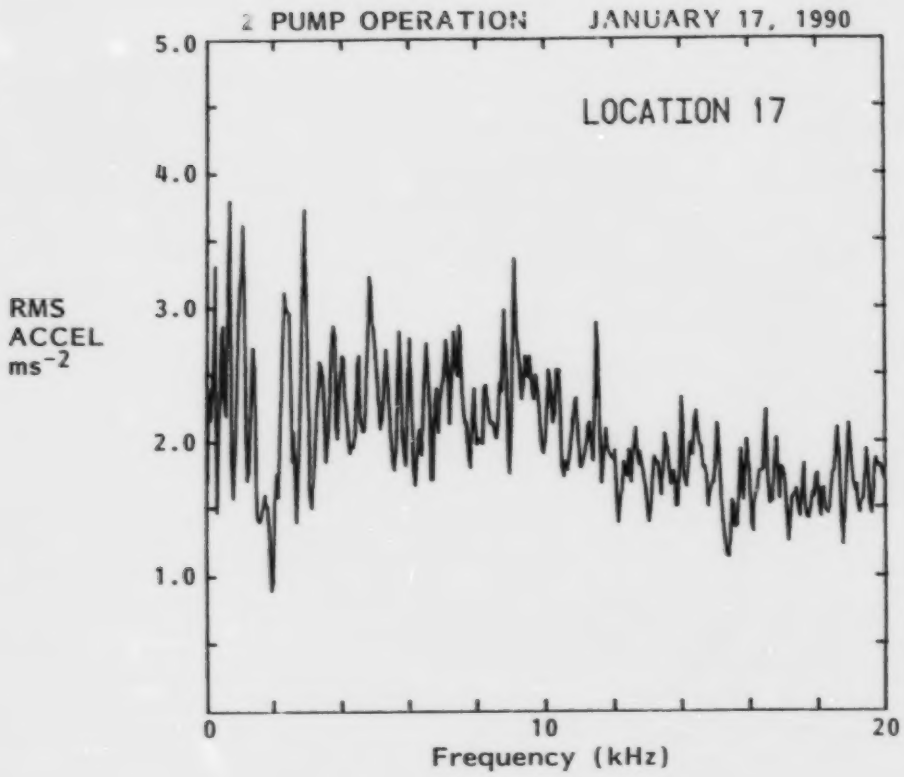


FIGURE 20

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

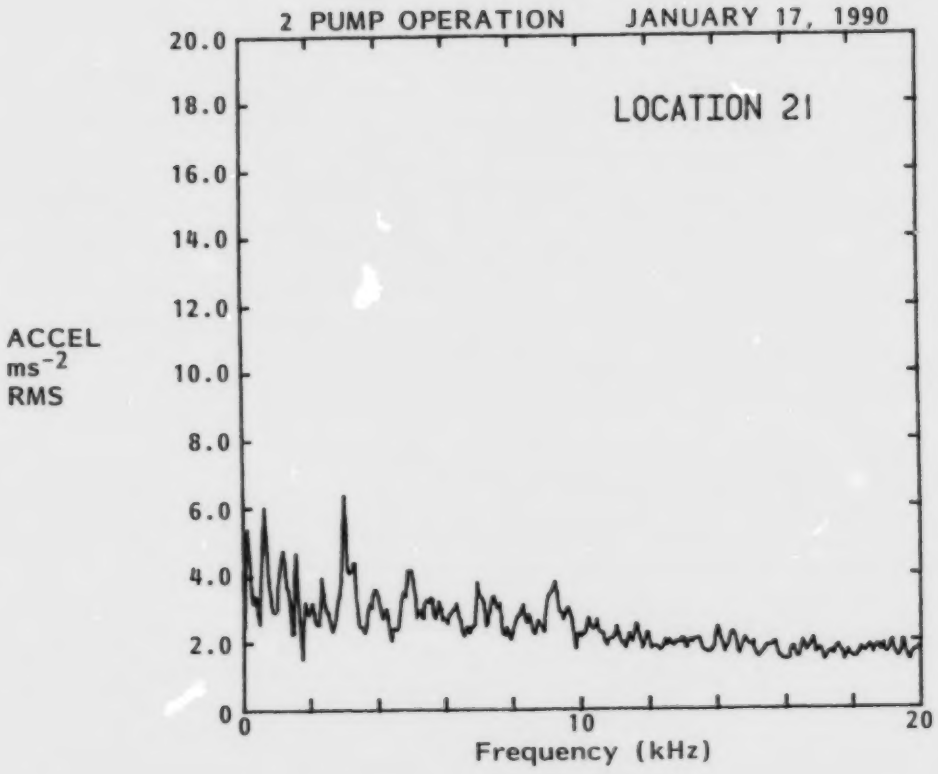


FIGURE 21

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

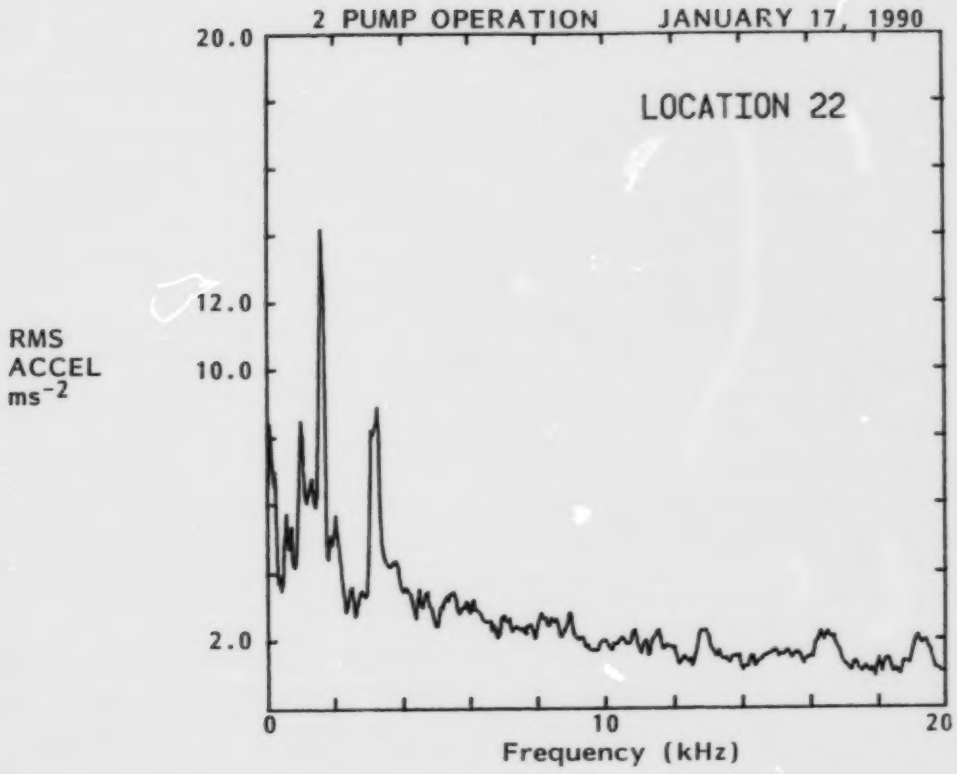


FIGURE 22

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

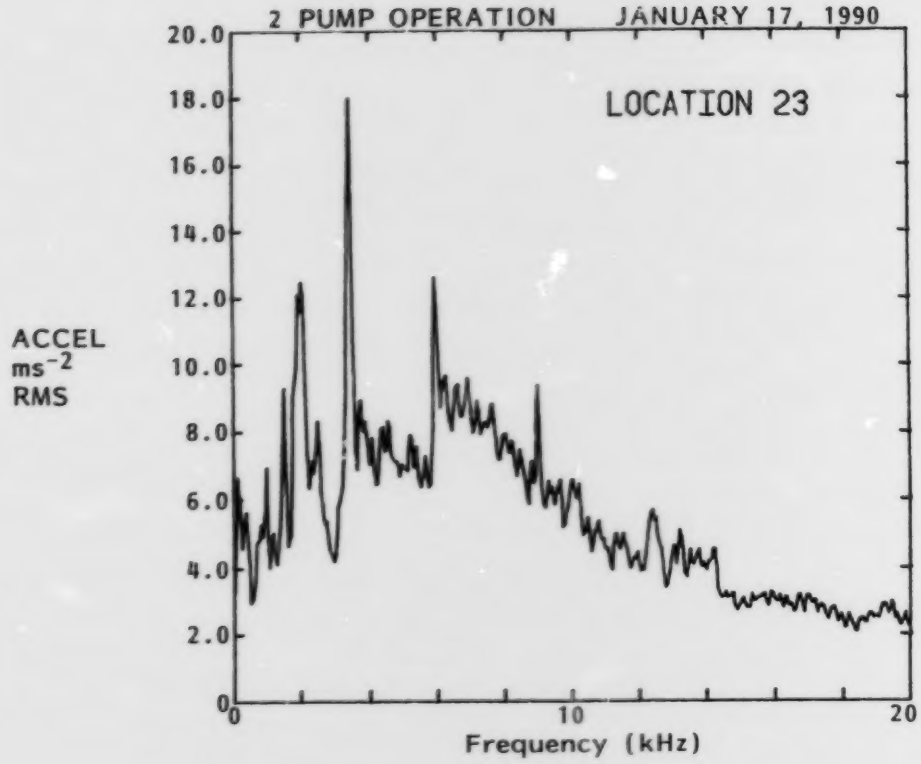


FIGURE 23

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

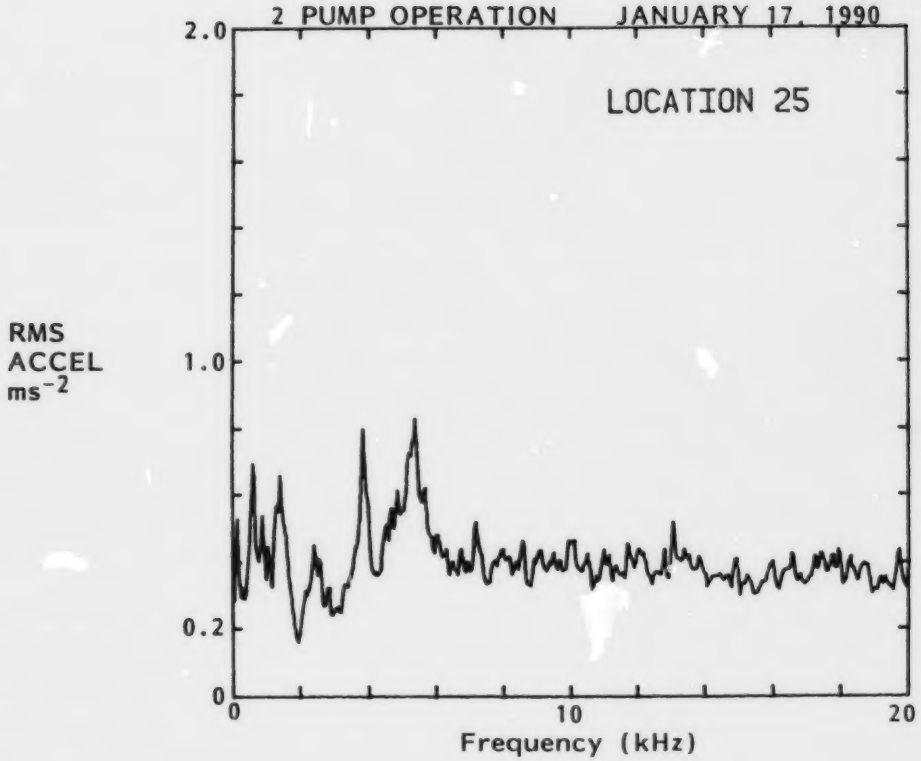


FIGURE 24

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

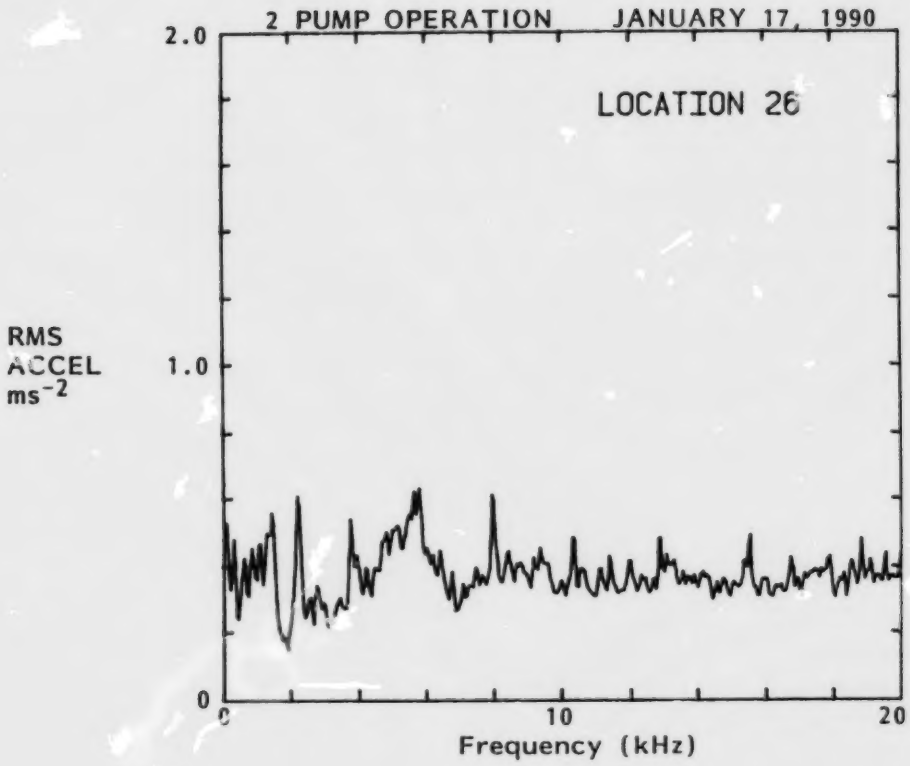


FIGURE 25

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

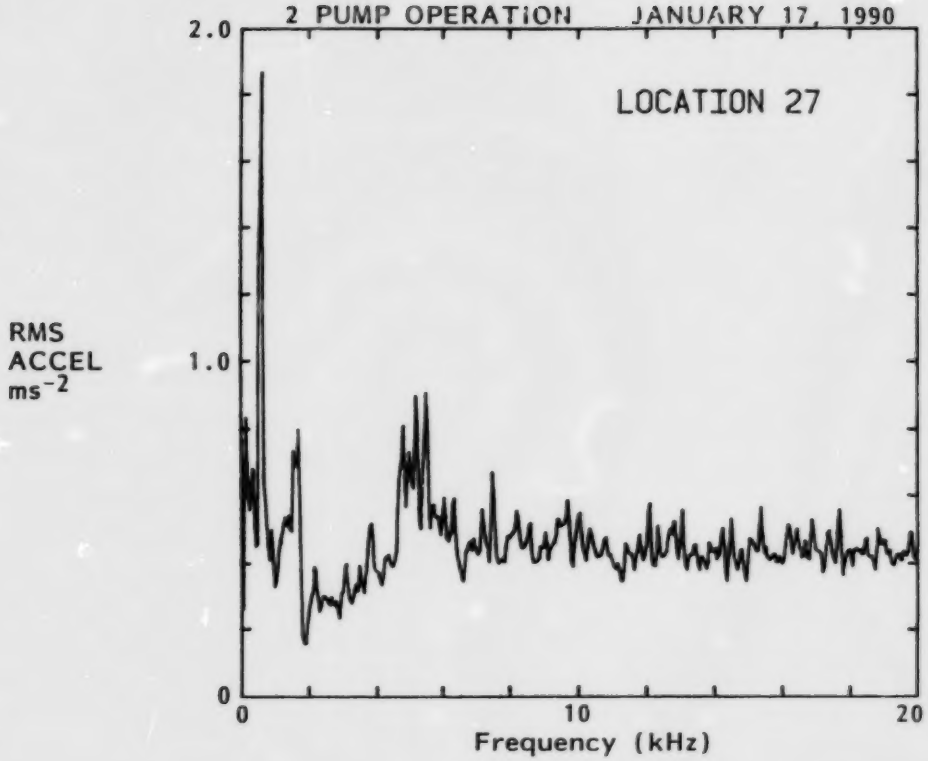


FIGURE 26

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

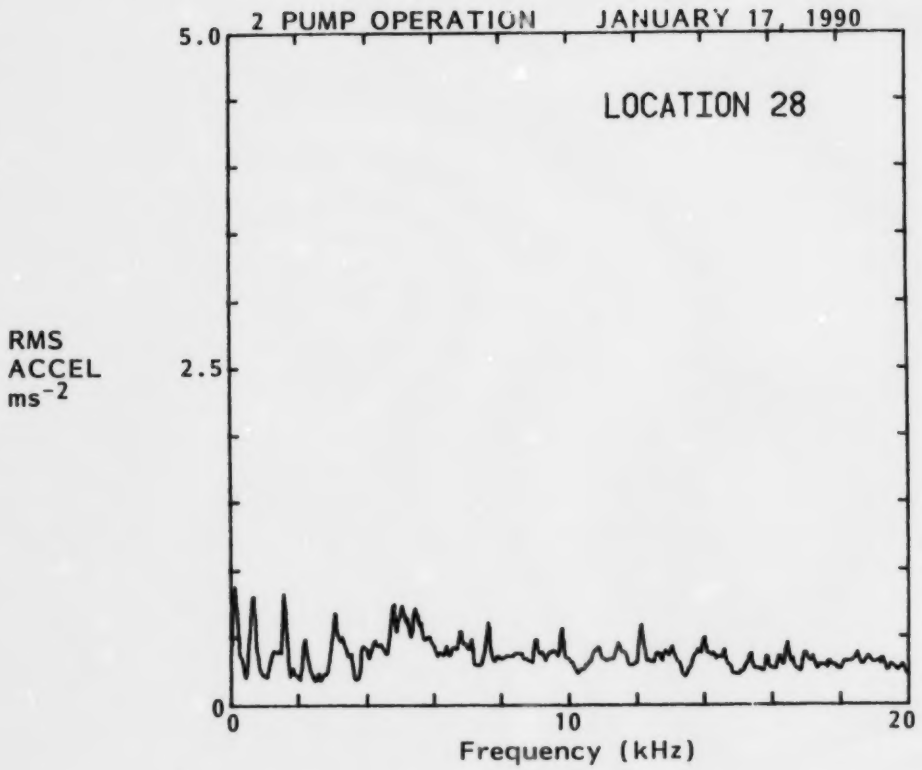


FIGURE 27

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

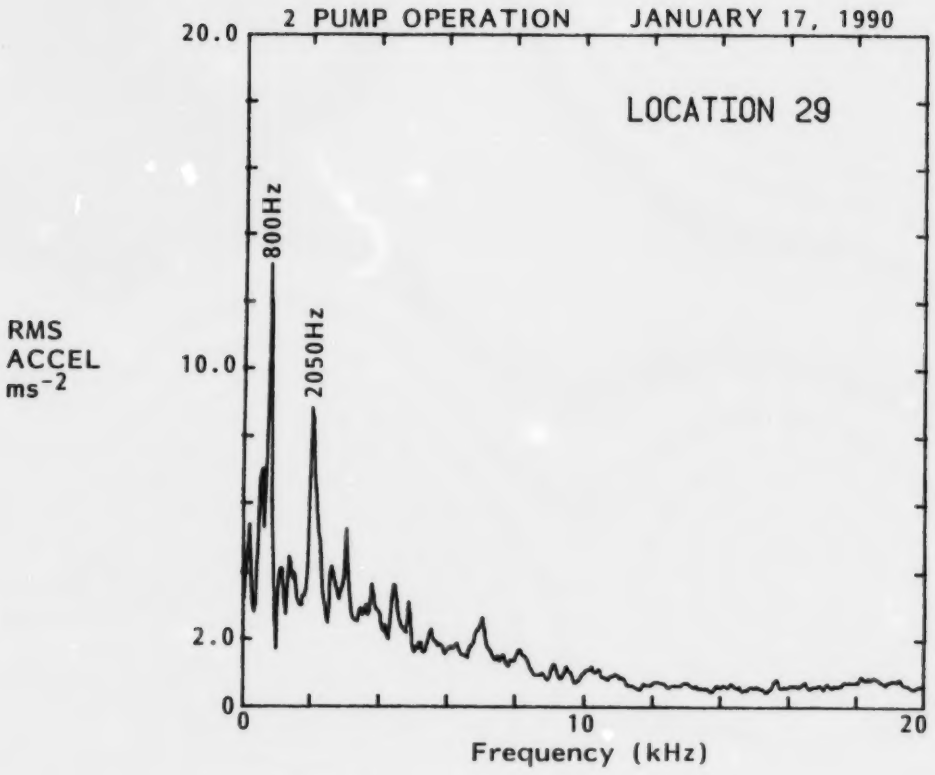


FIGURE 28

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

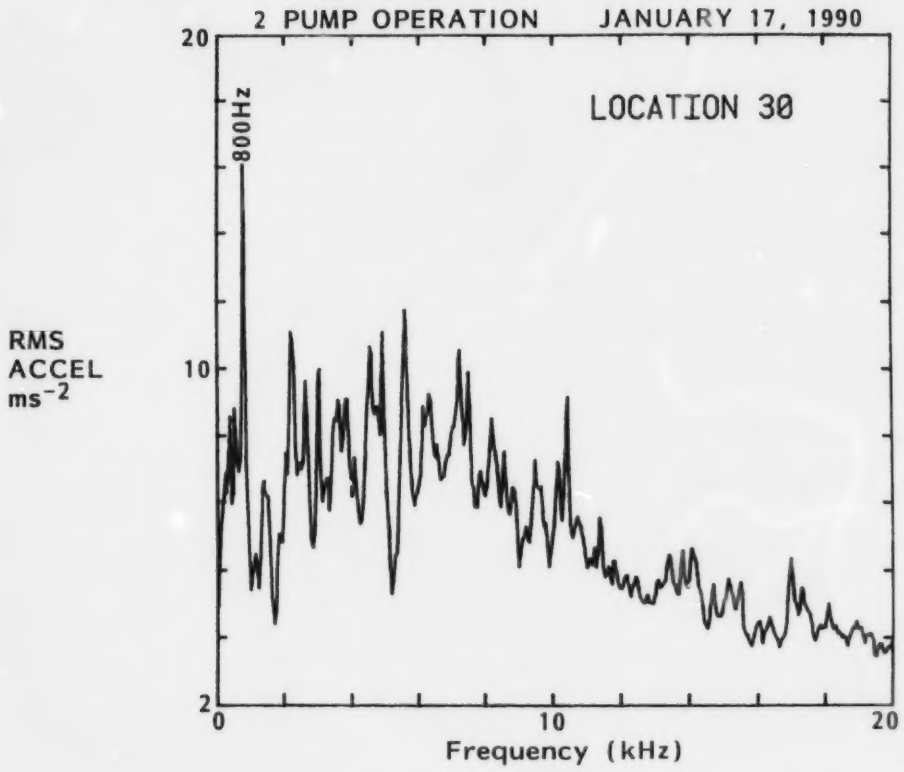


FIGURE 29

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

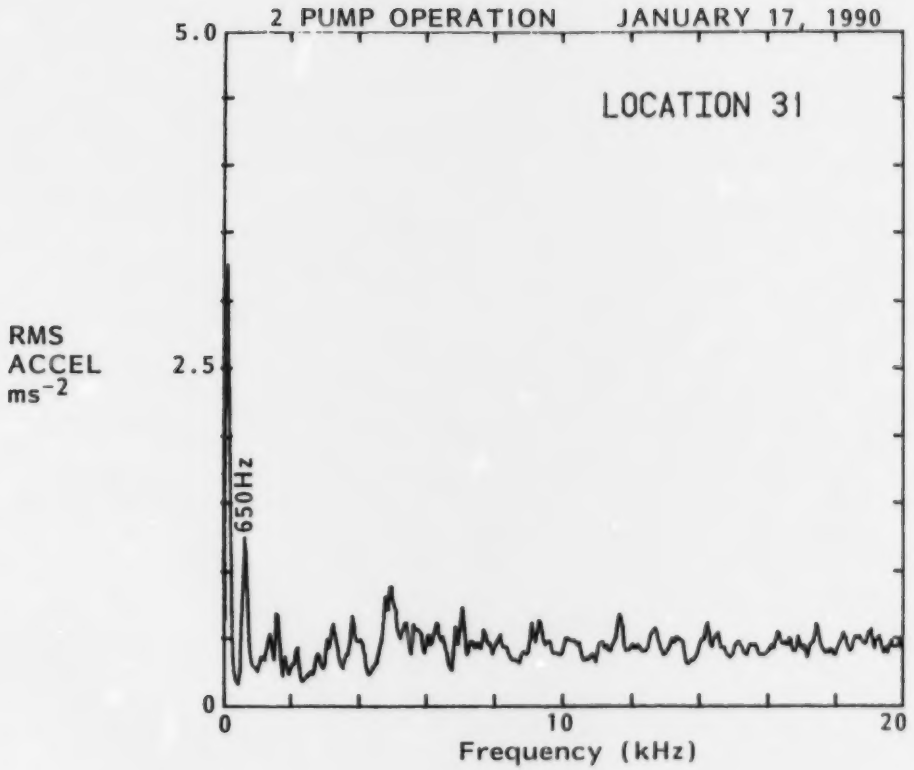


FIGURE 30

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

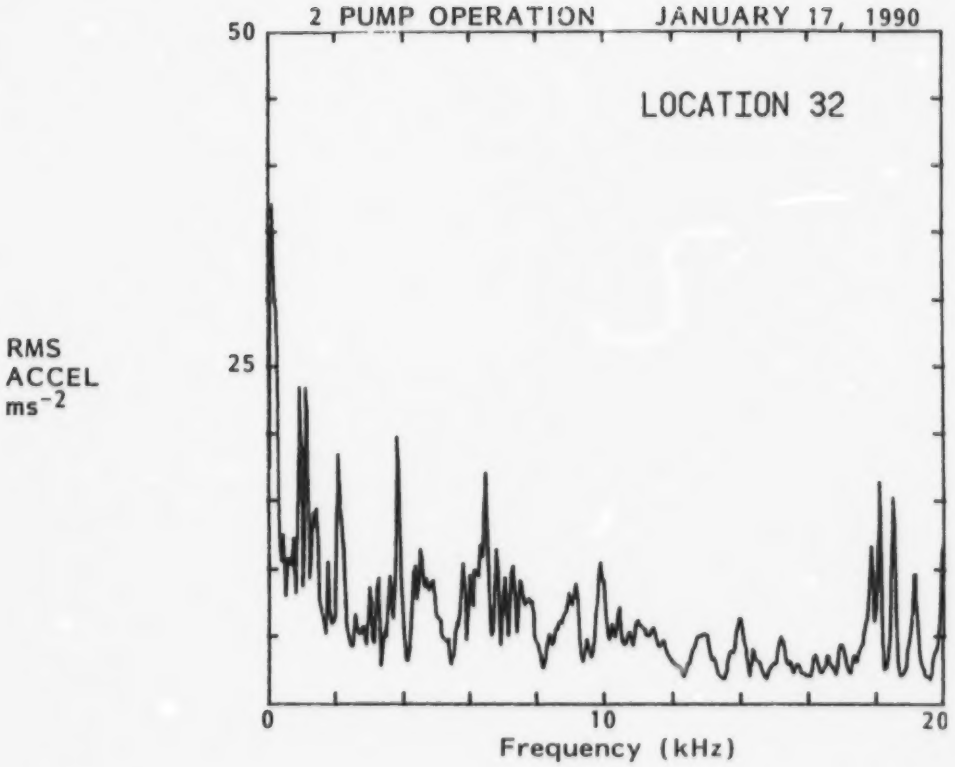


FIGURE 31

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

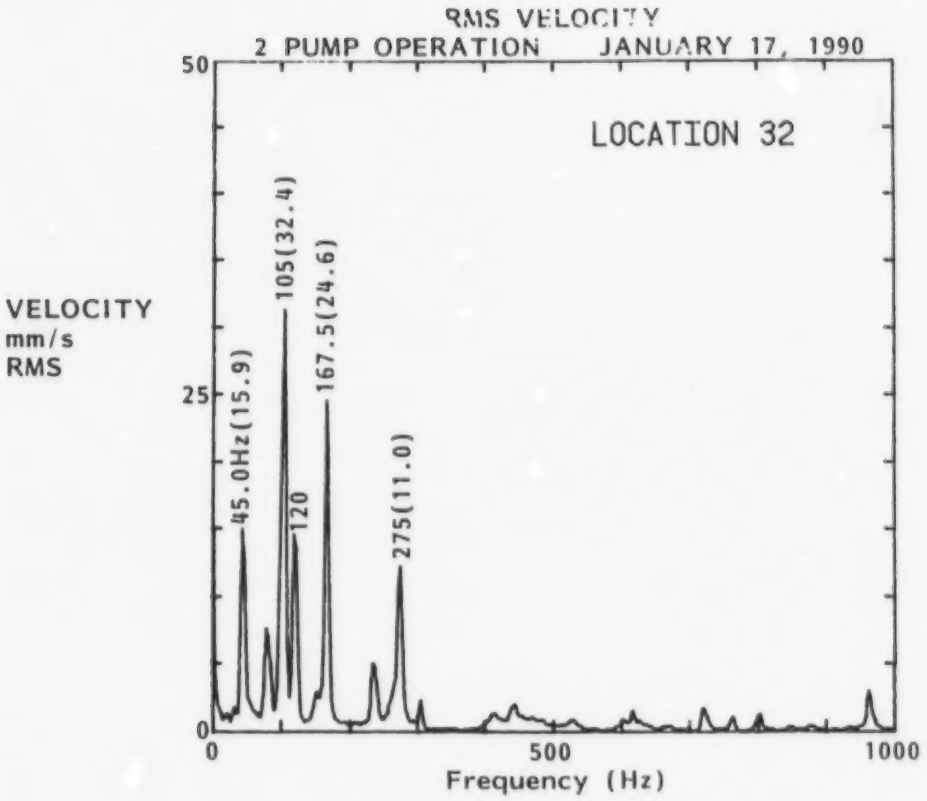


FIGURE 32

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

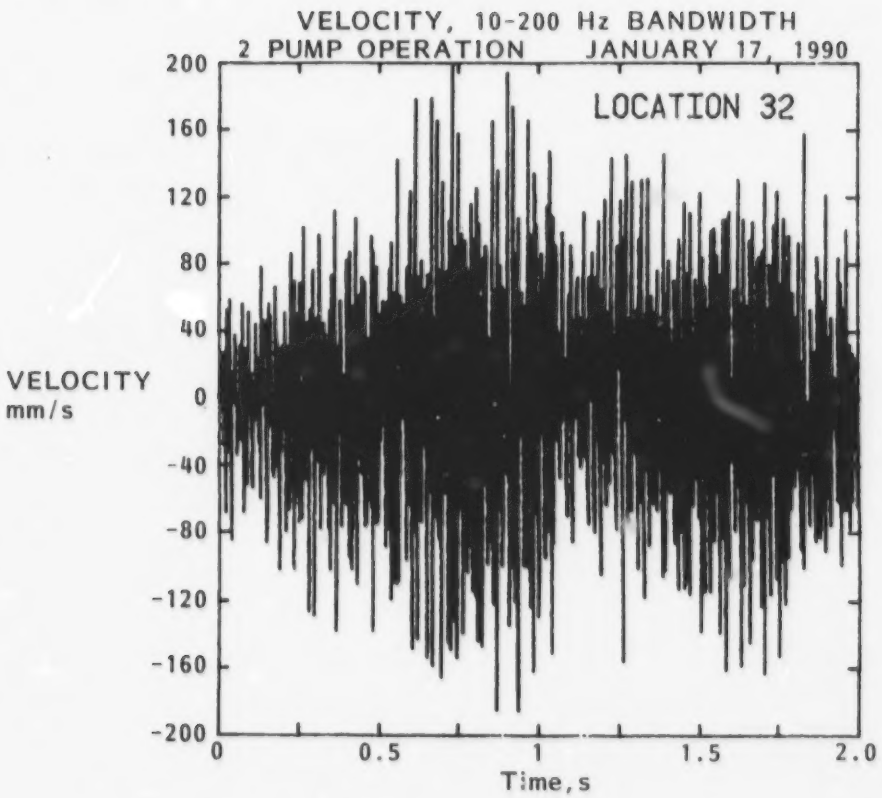


FIGURE 33

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

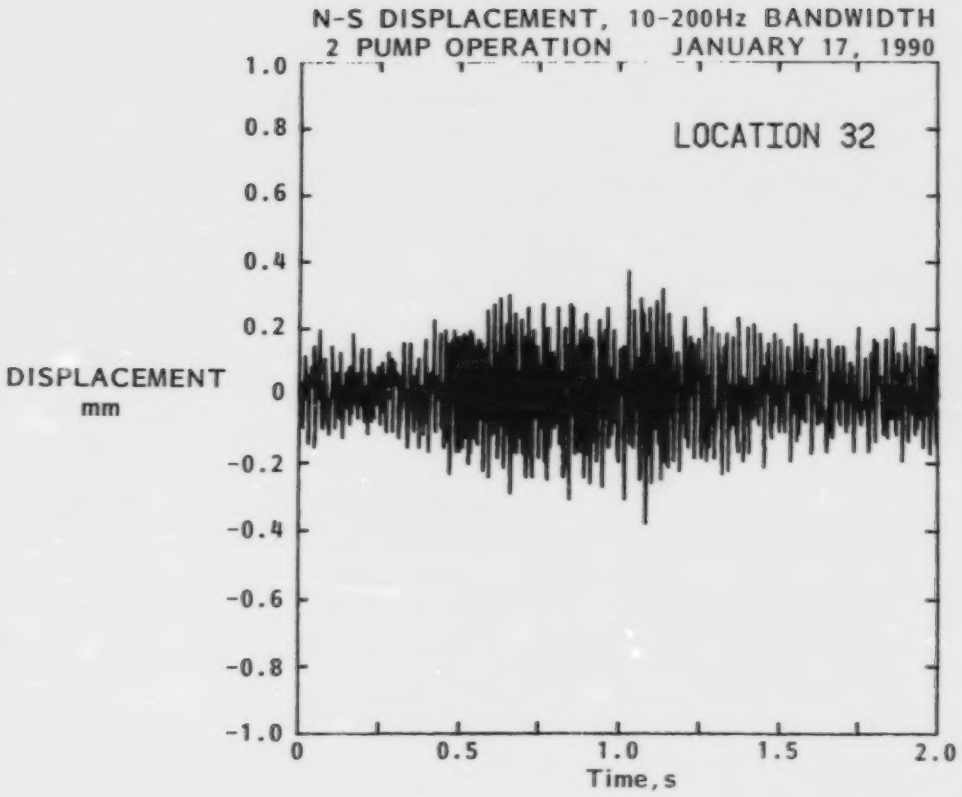


FIGURE 34

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

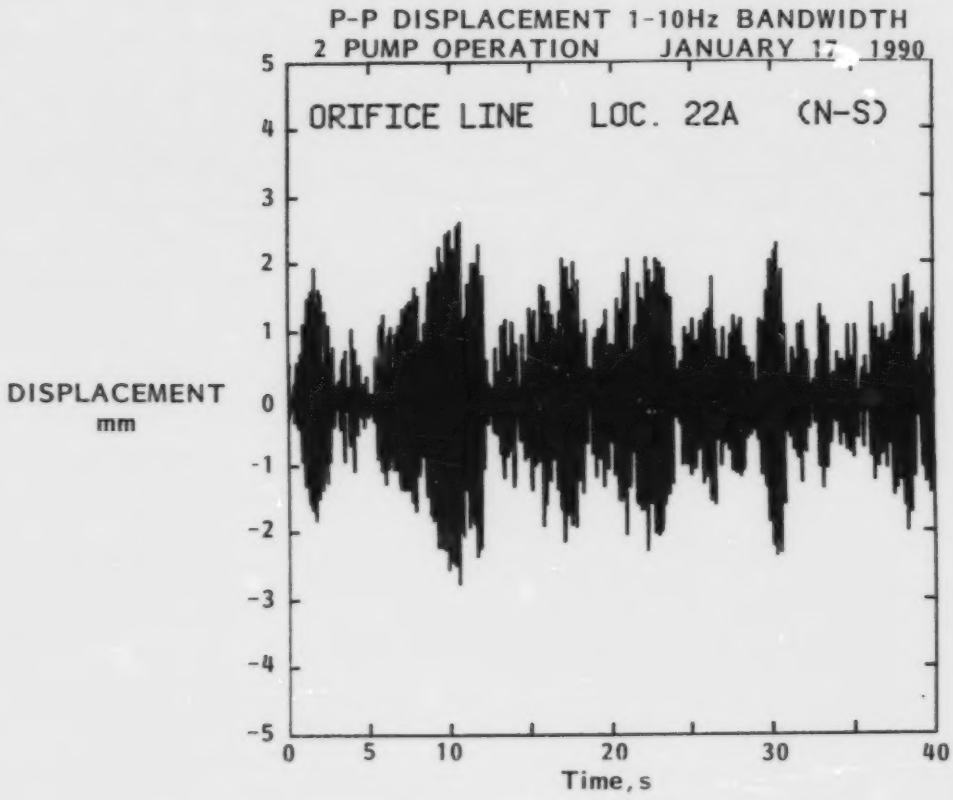


FIGURE 35
BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

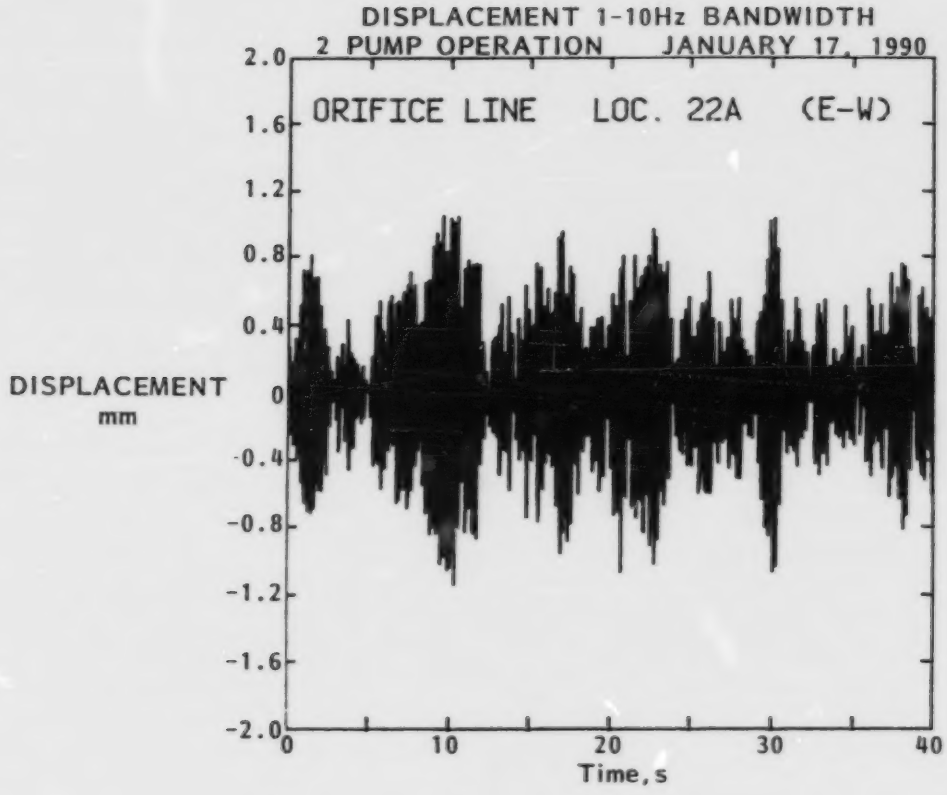


FIGURE 36

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

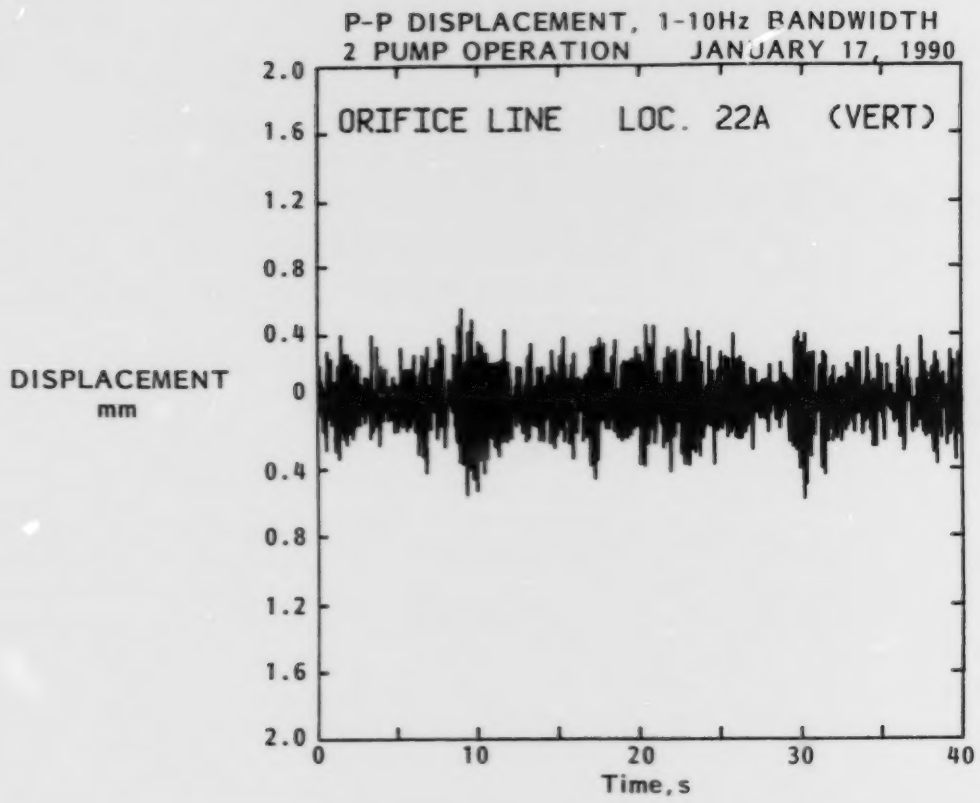


FIGURE 37

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

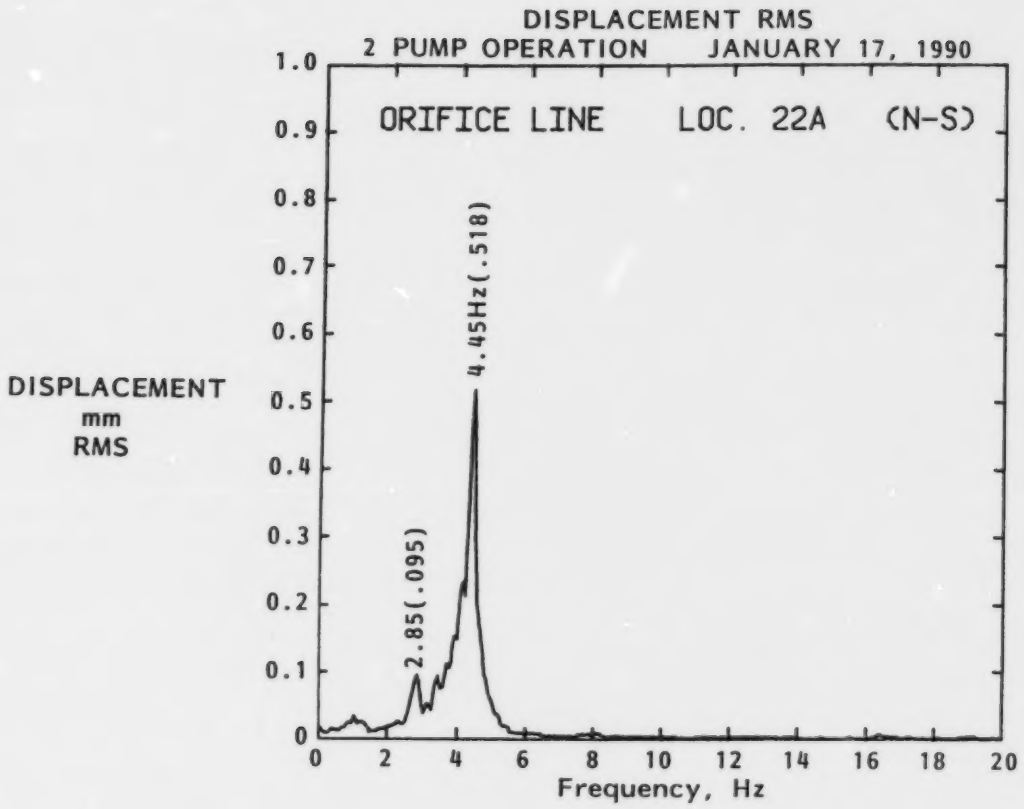


FIGURE 38

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

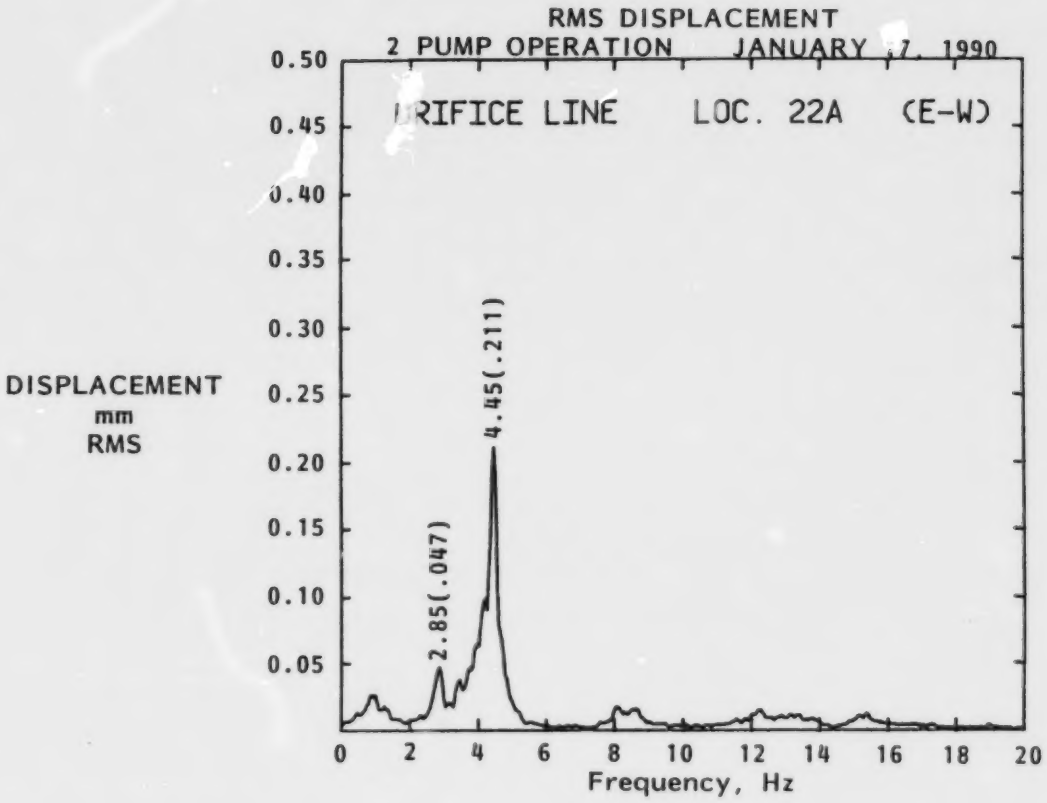


FIGURE 39

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

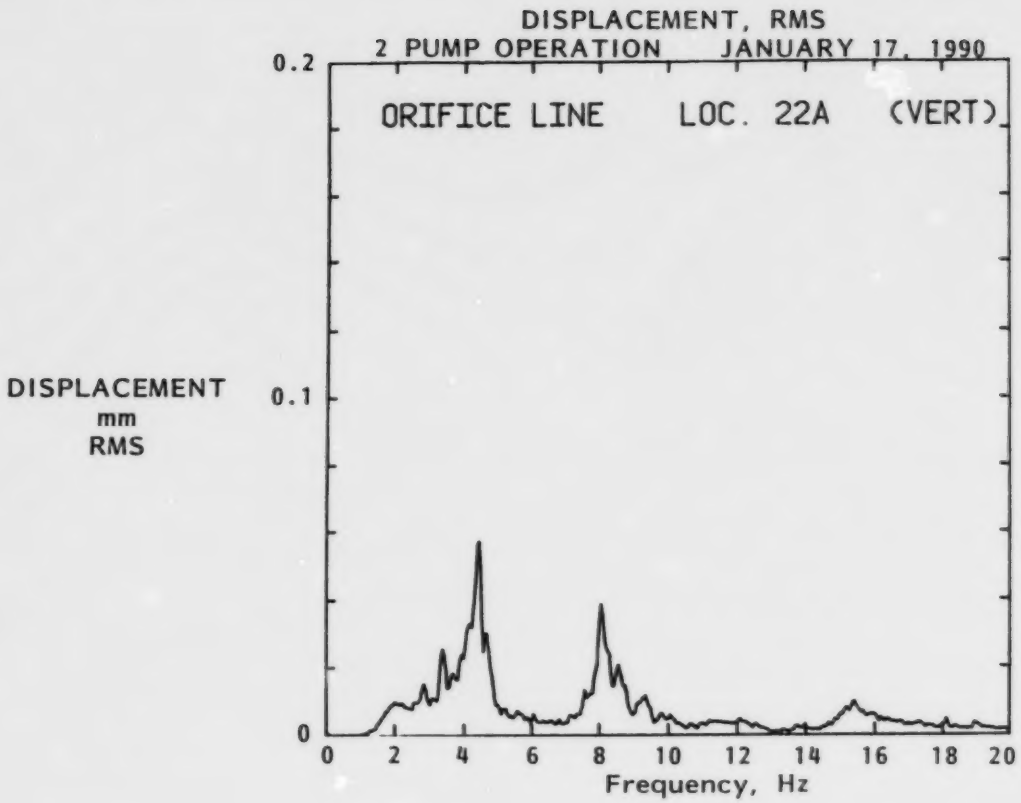


FIGURE 40

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

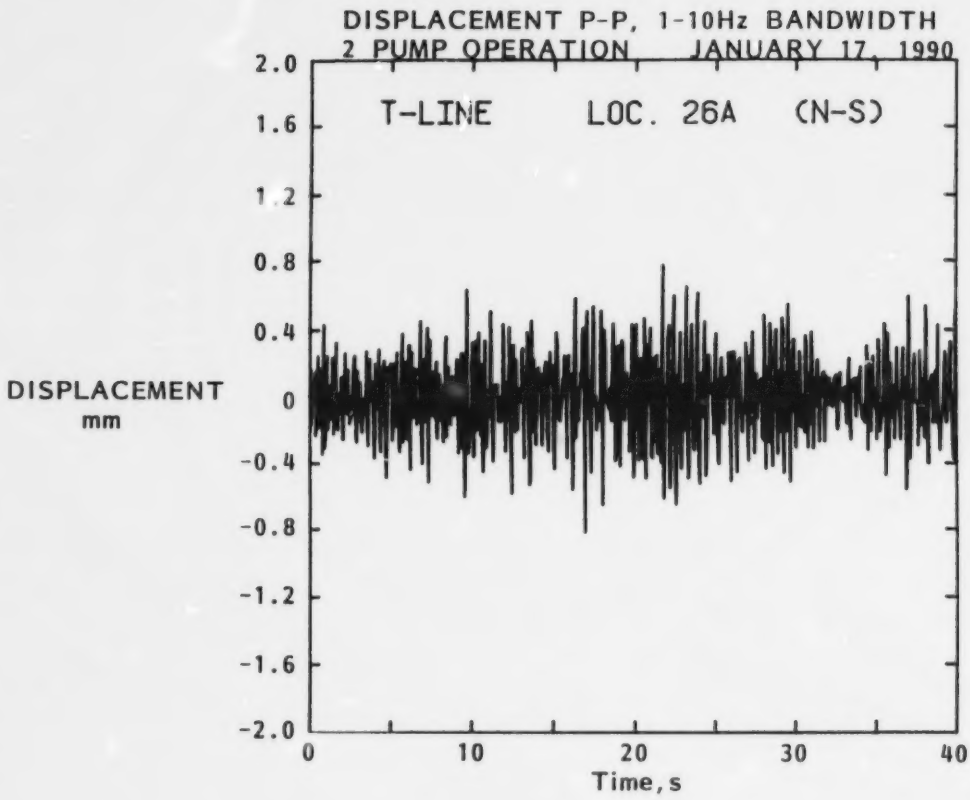


FIGURE 41

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

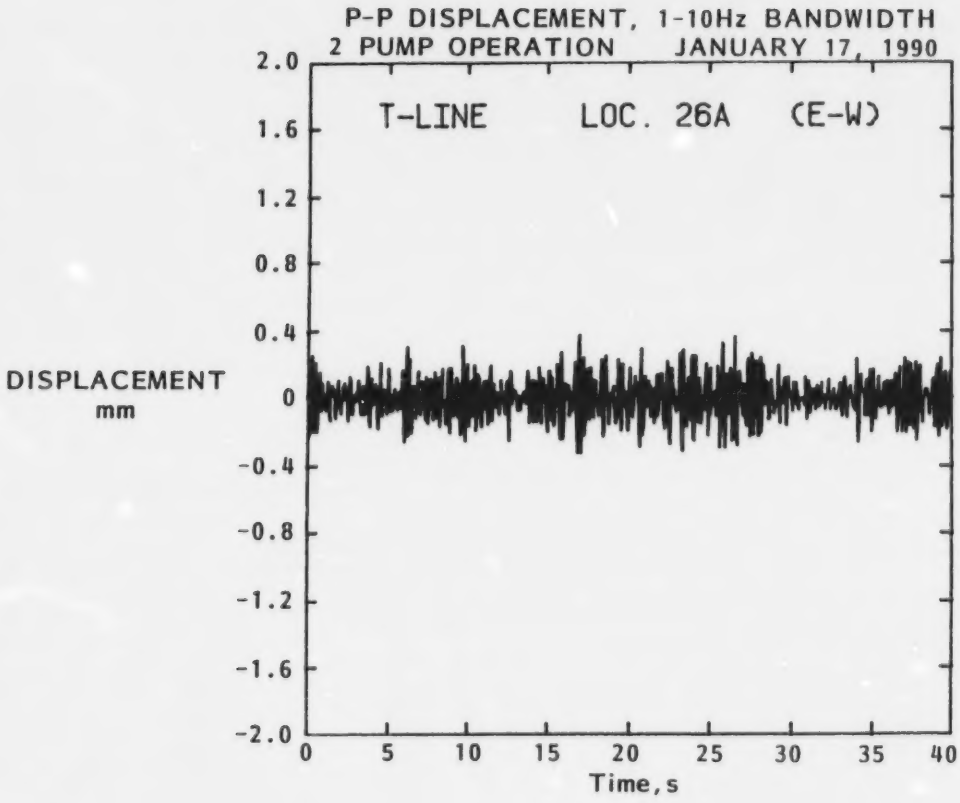


FIGURE 42

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

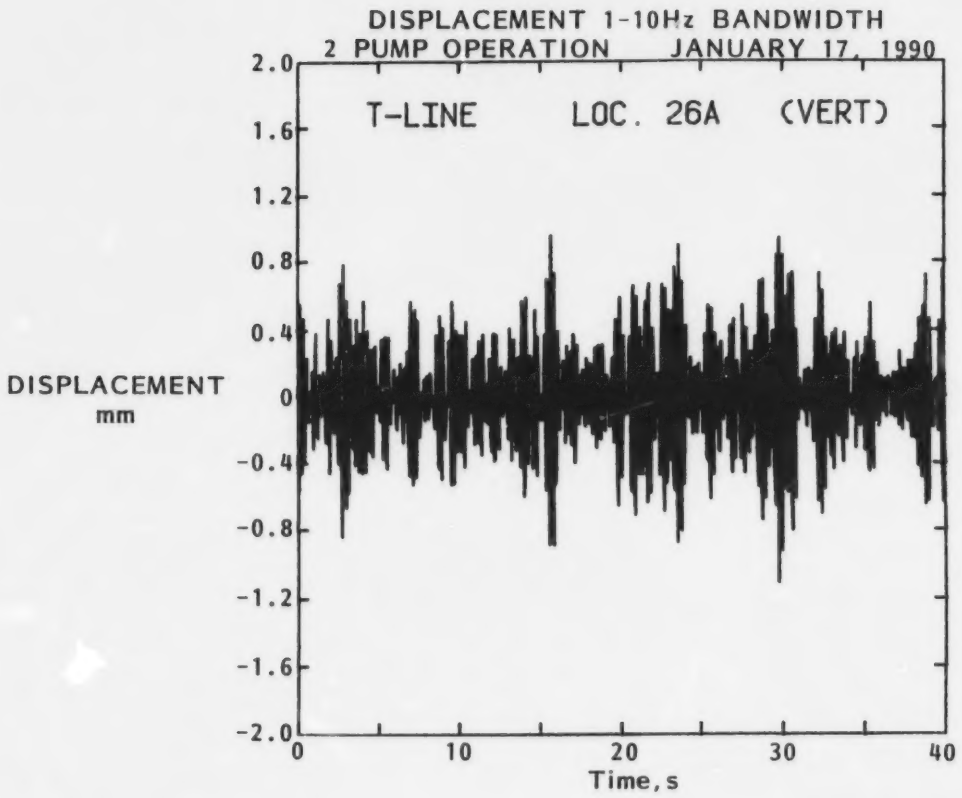


FIGURE 43

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

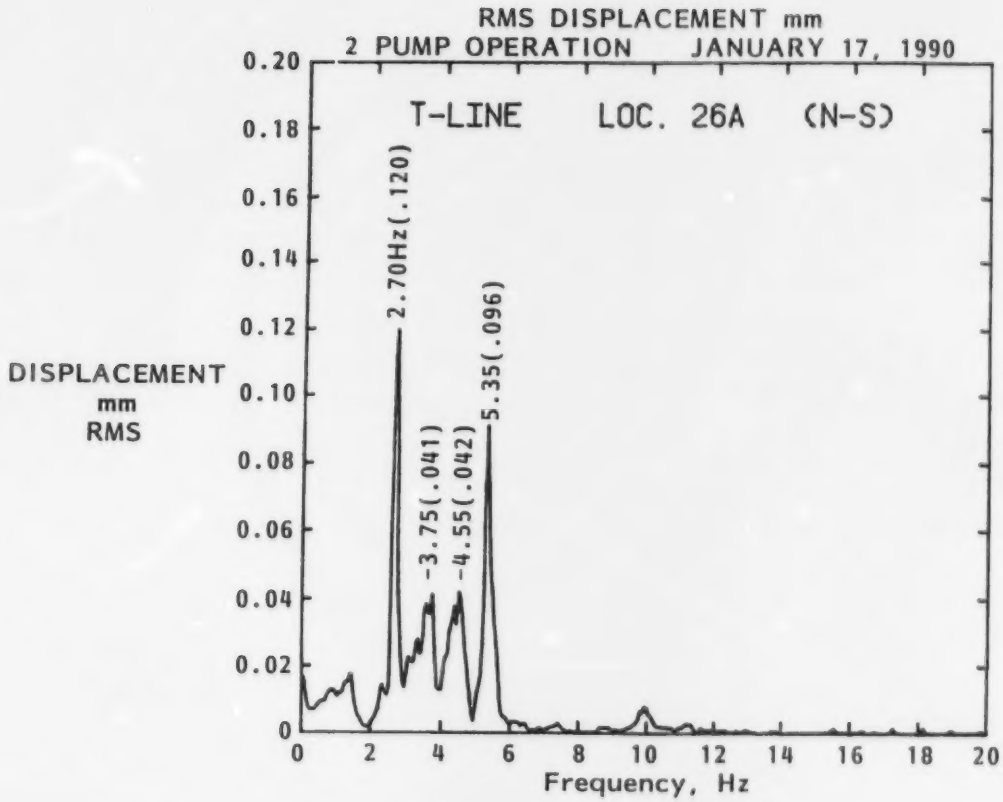


FIGURE 44

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

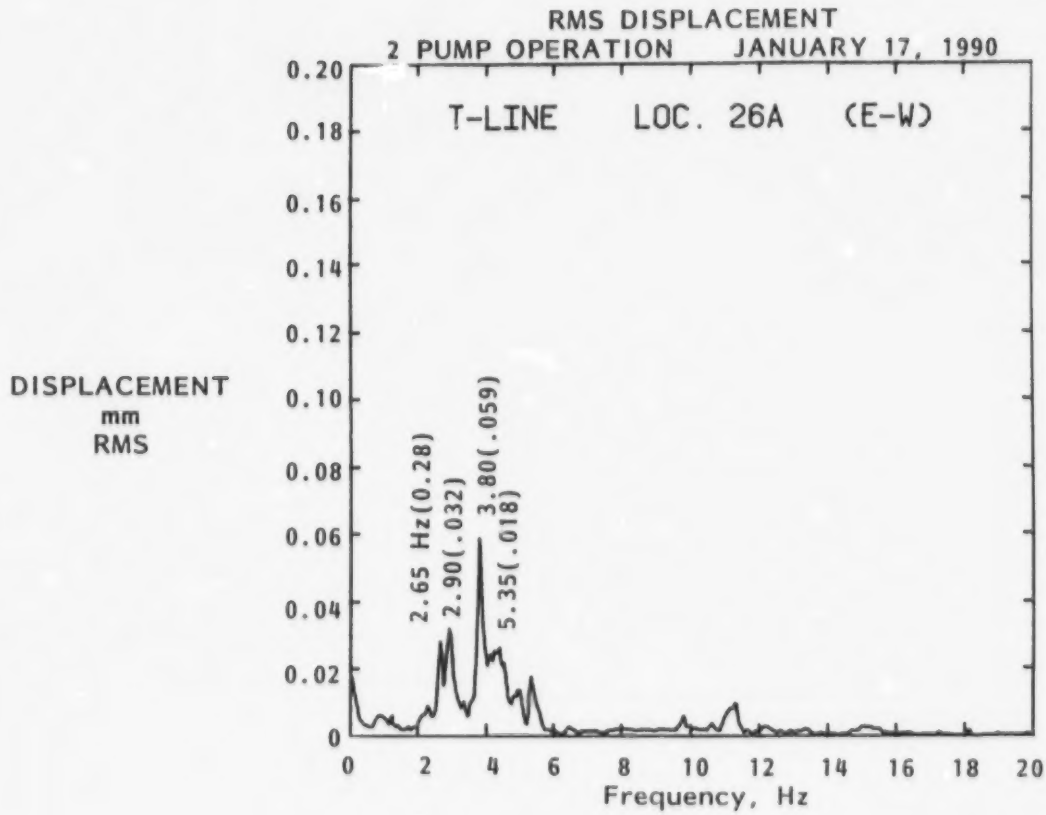


FIGURE 45

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

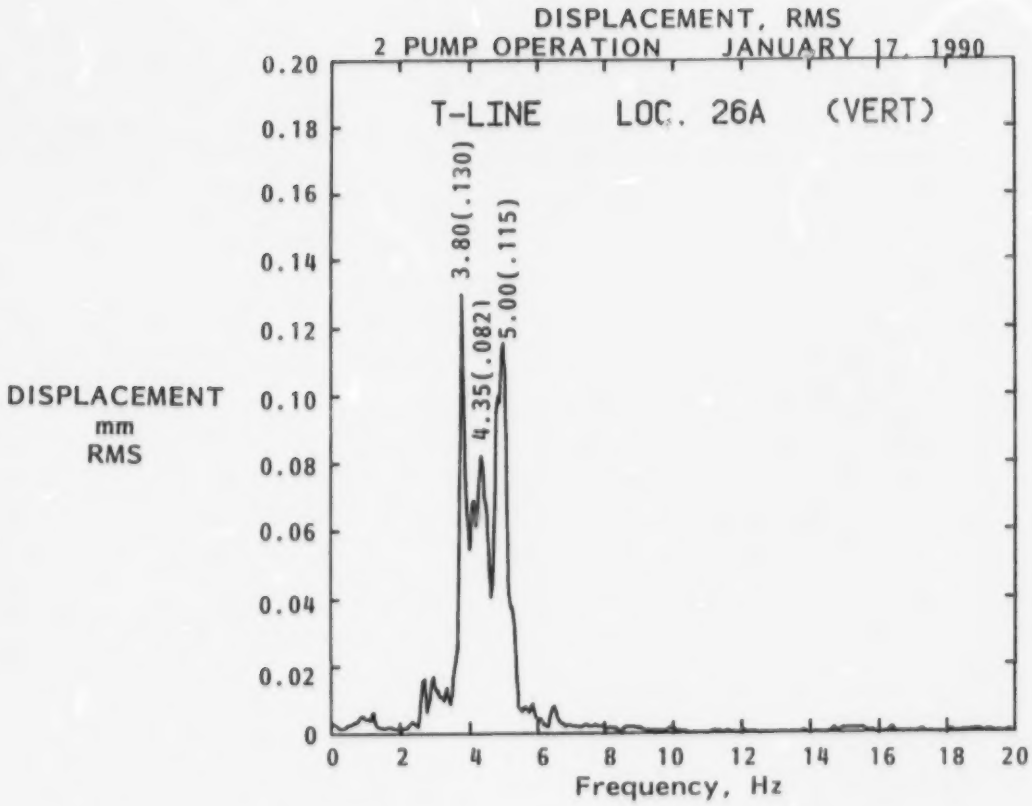


FIGURE 46

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

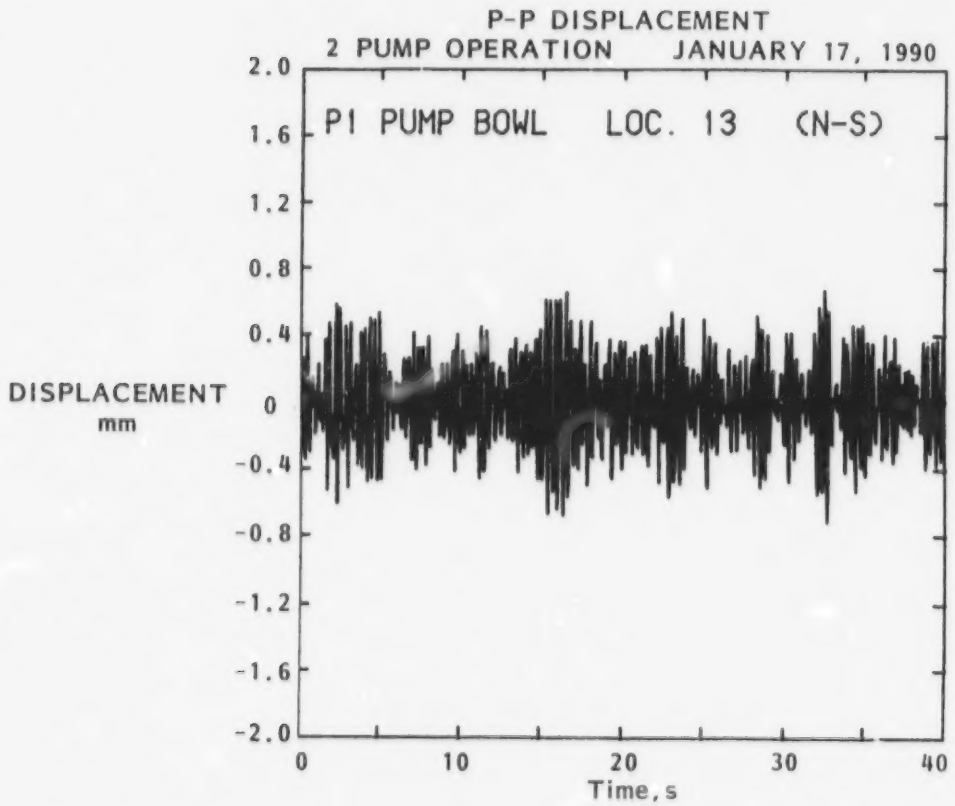


FIGURE 47
BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

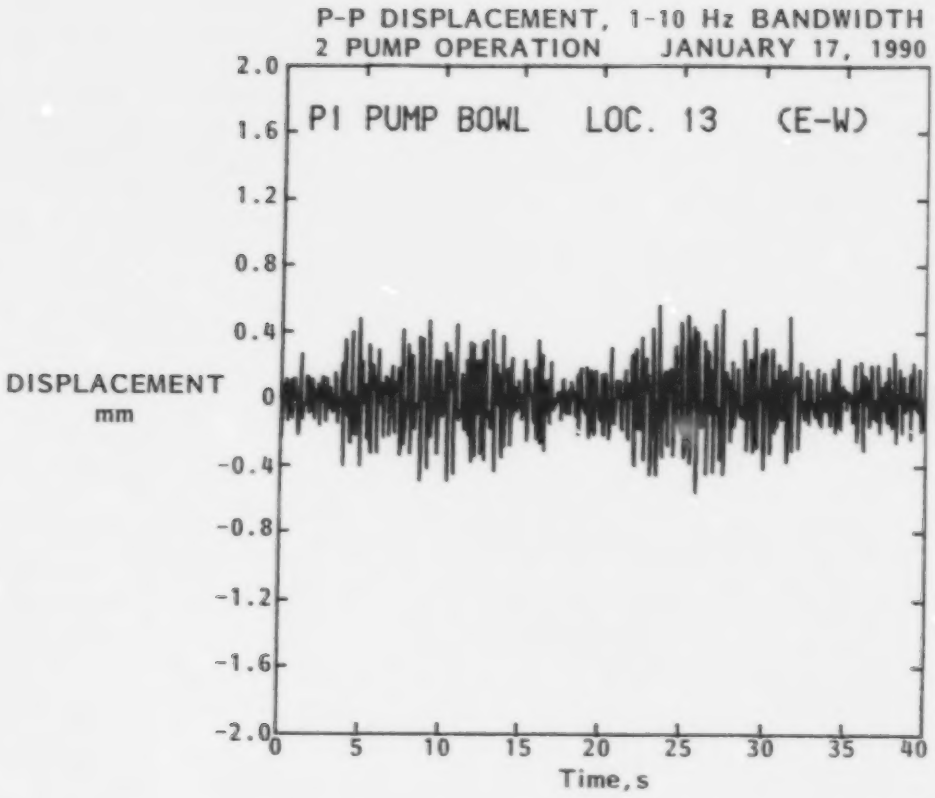


FIGURE 48

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

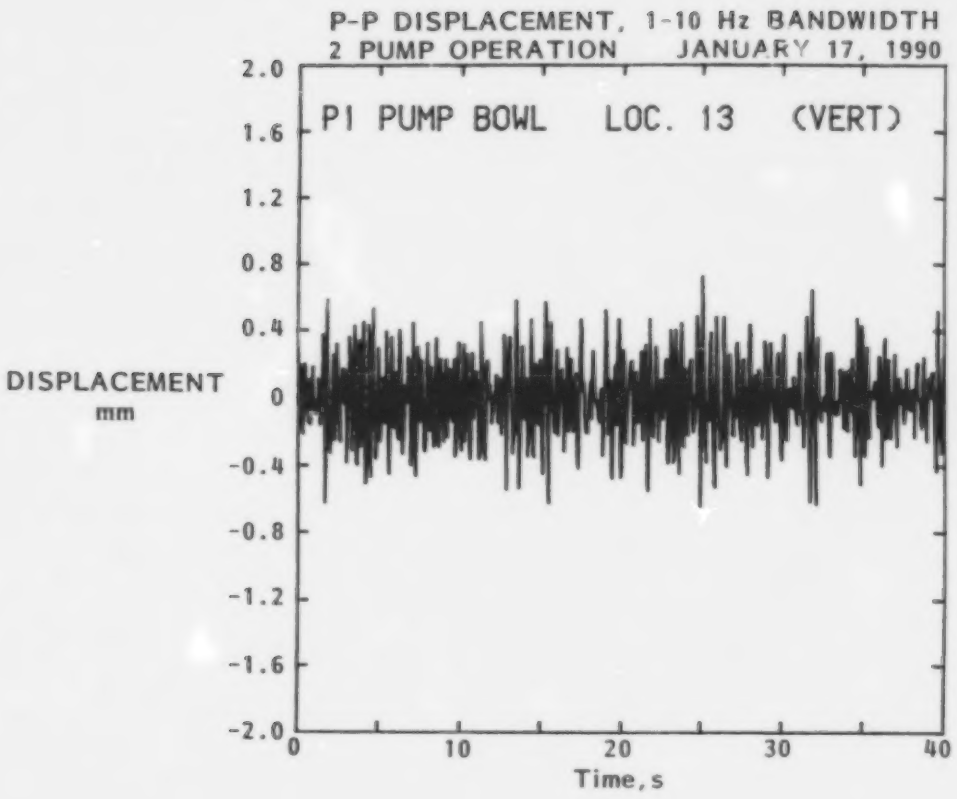


FIGURE 49

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

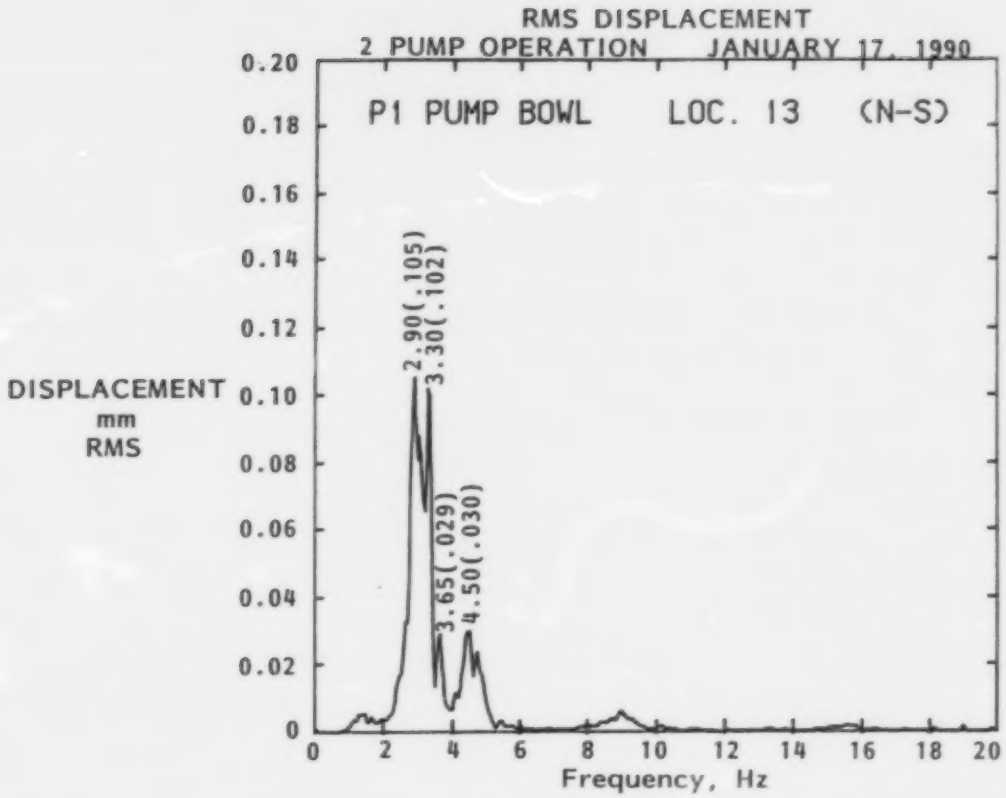


FIGURE 50

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

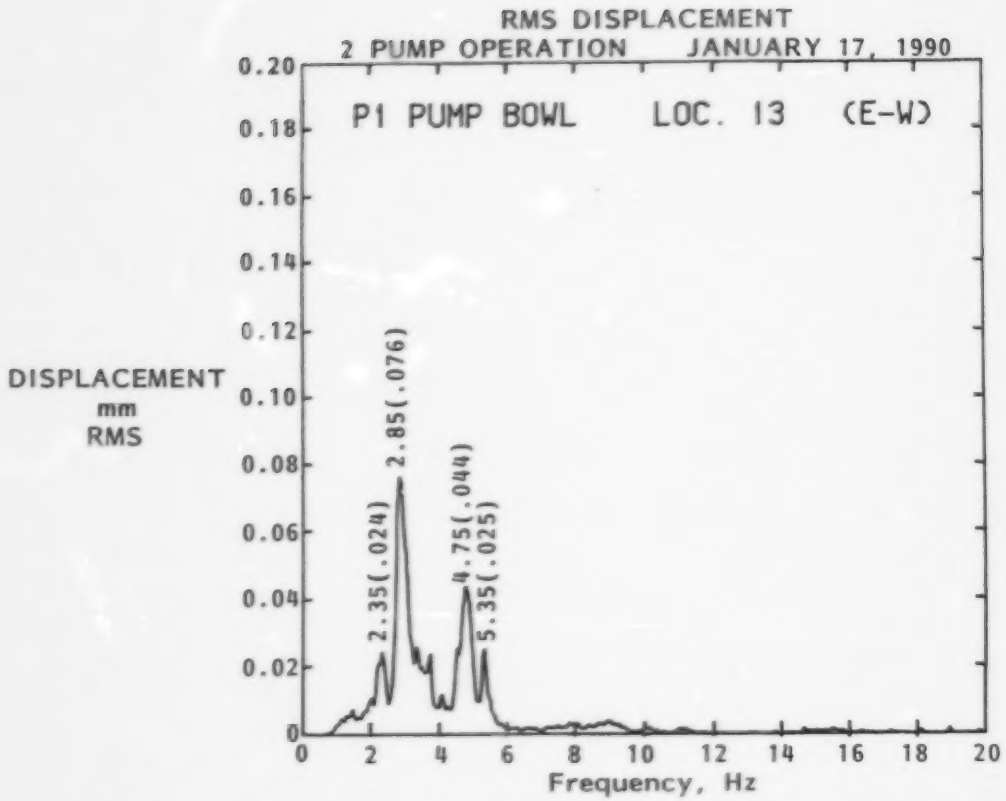


FIGURE 51

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

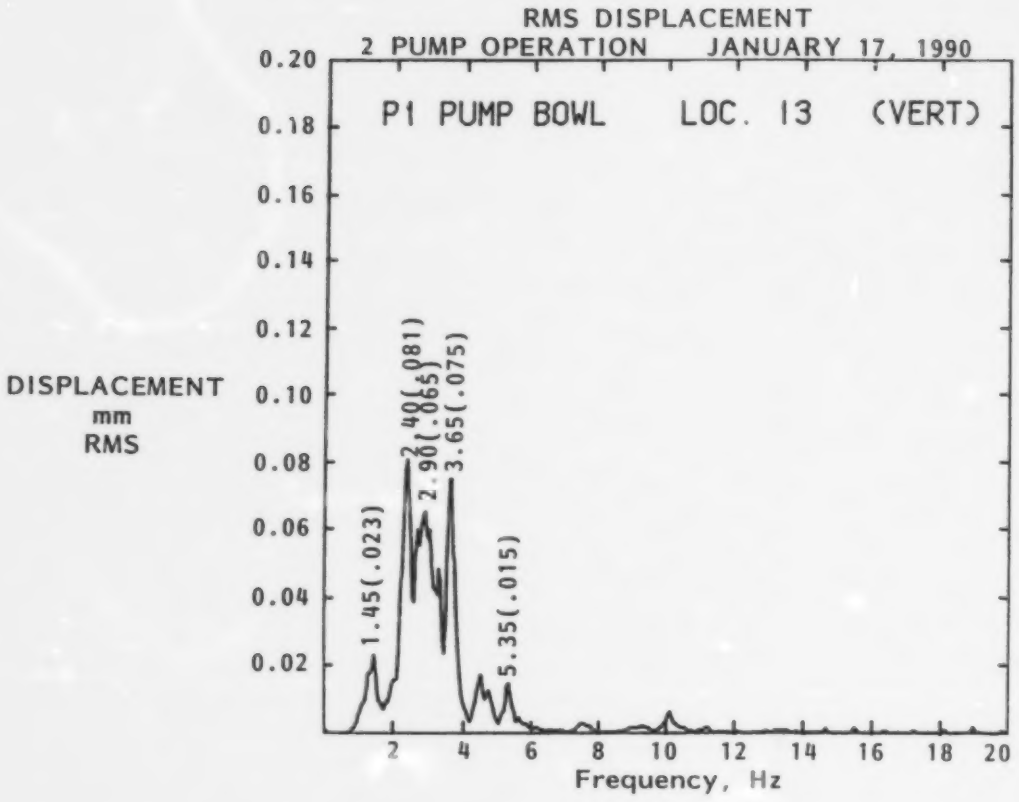


FIGURE 52

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

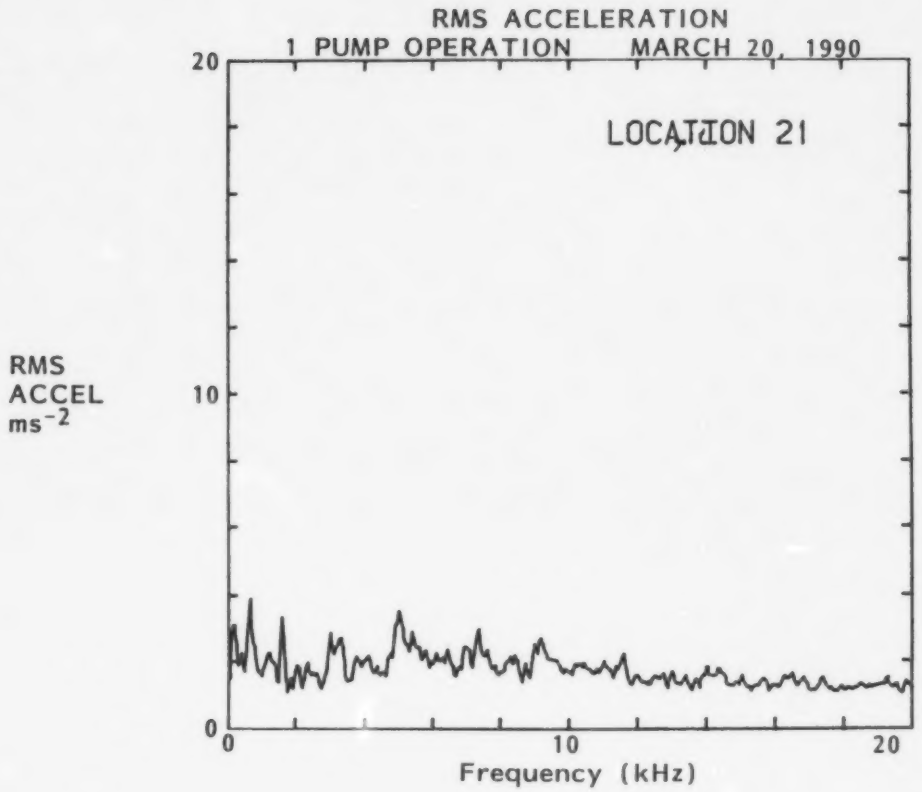


FIGURE 53

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

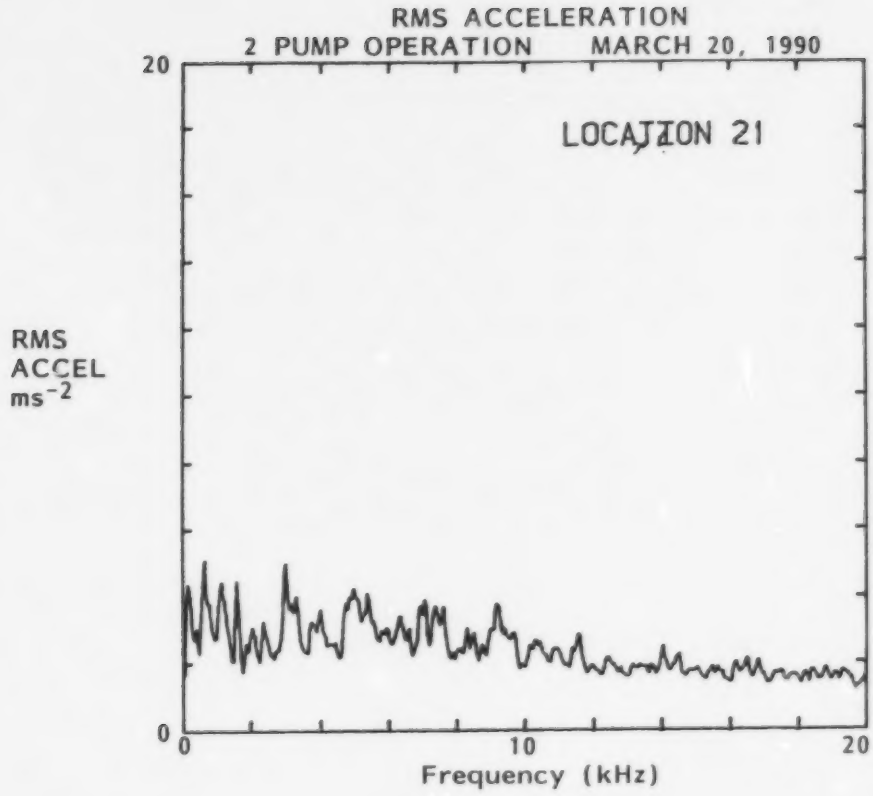


FIGURE 54

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

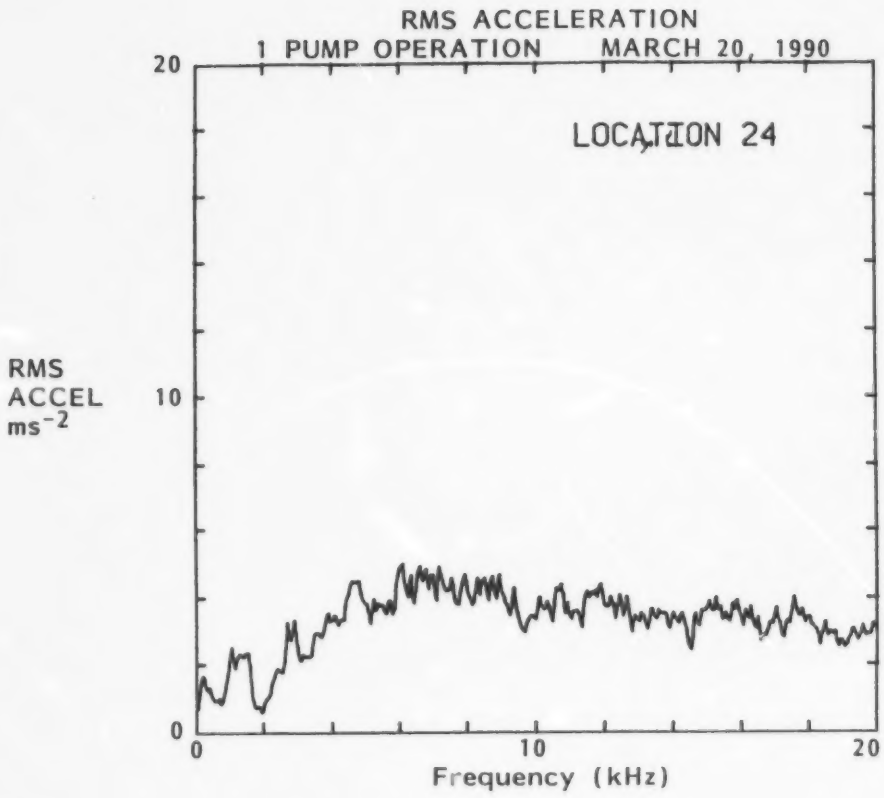


FIGURE 55

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

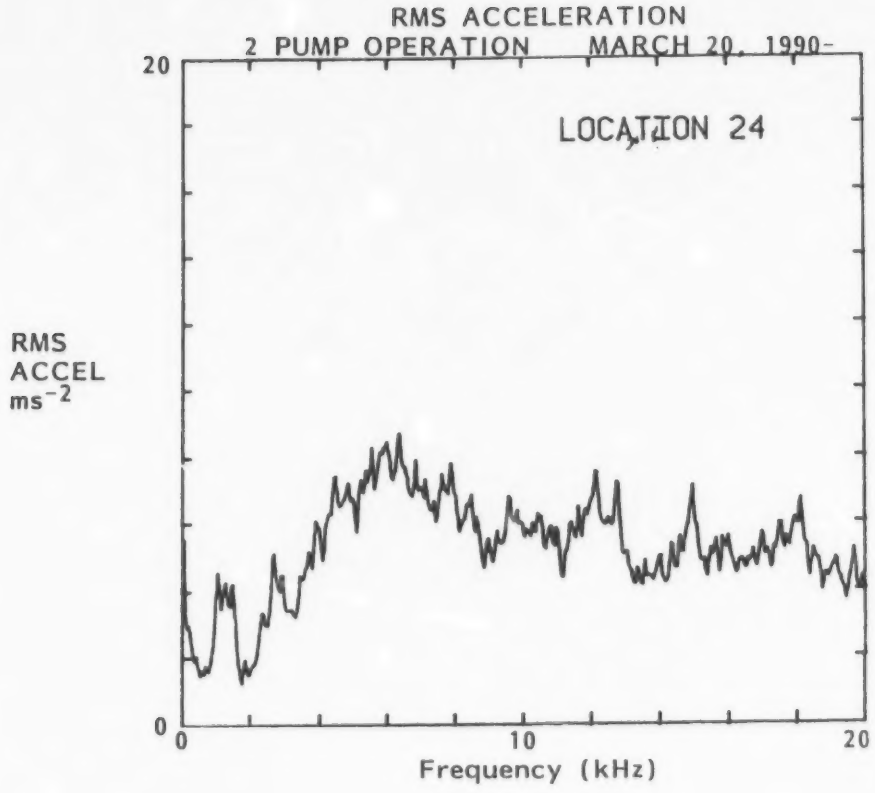


FIGURE 56

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

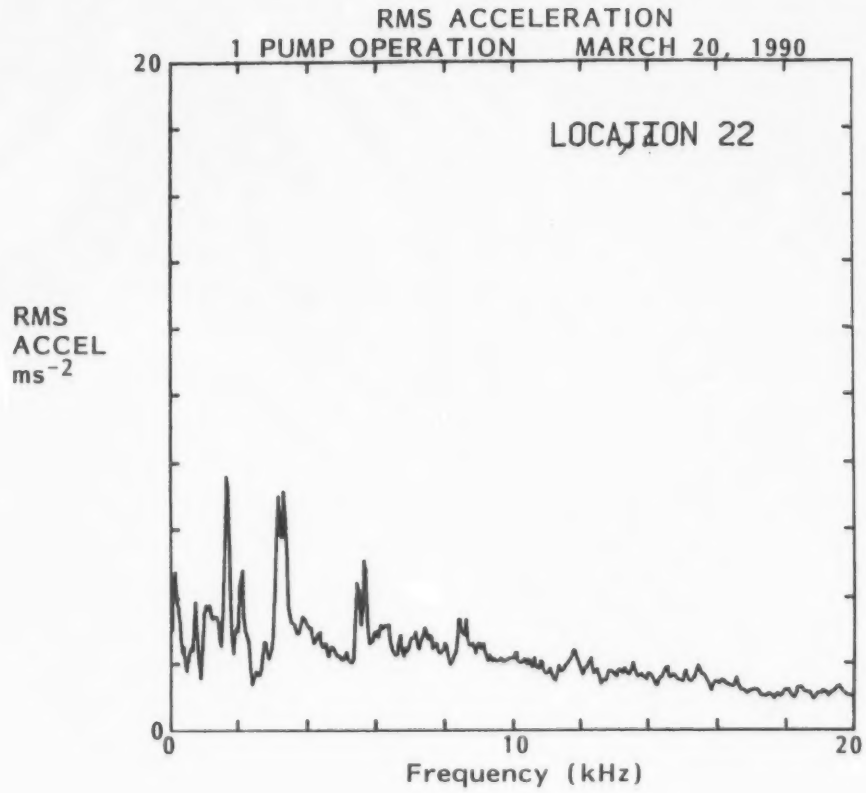


FIGURE 57

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

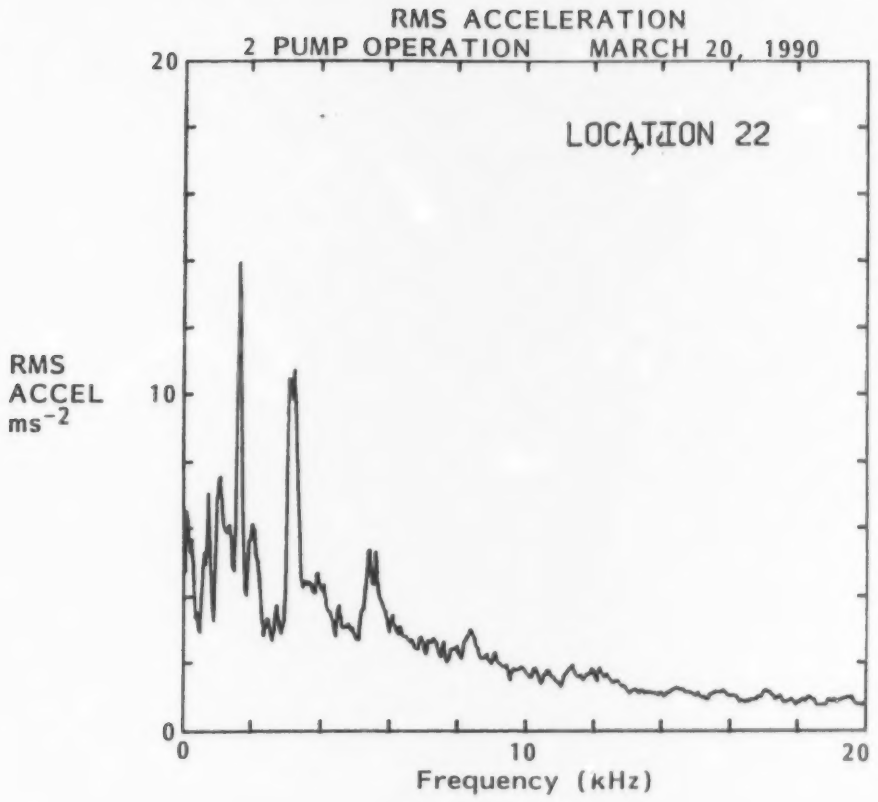


FIGURE 58

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

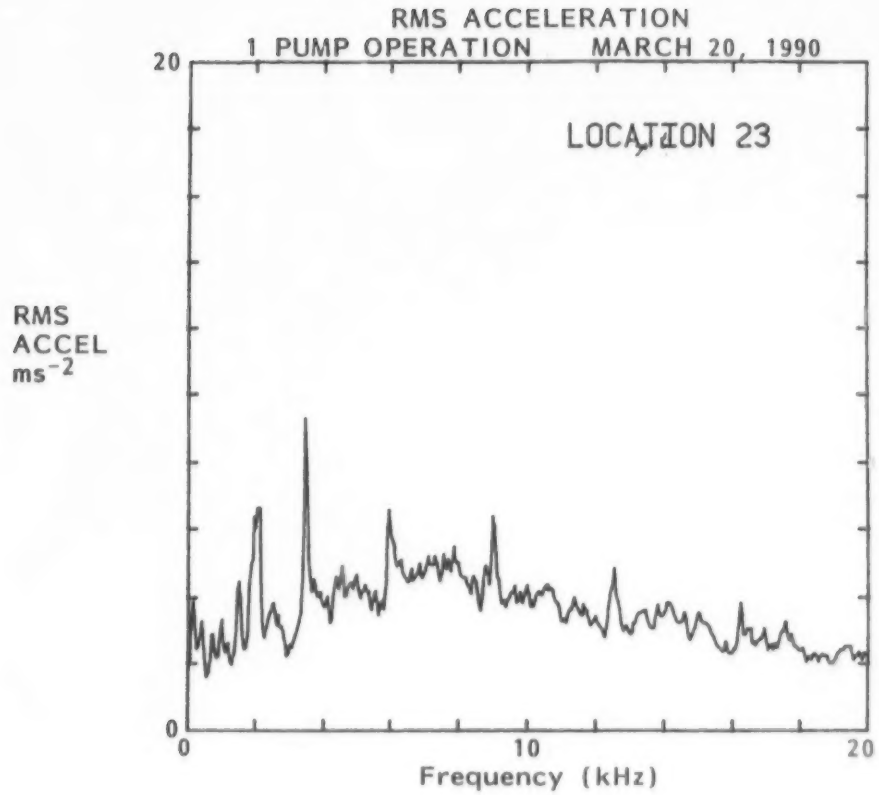


FIGURE 59

BNGS U2 MAINTENANCE COOLING PIPING VIBRATION

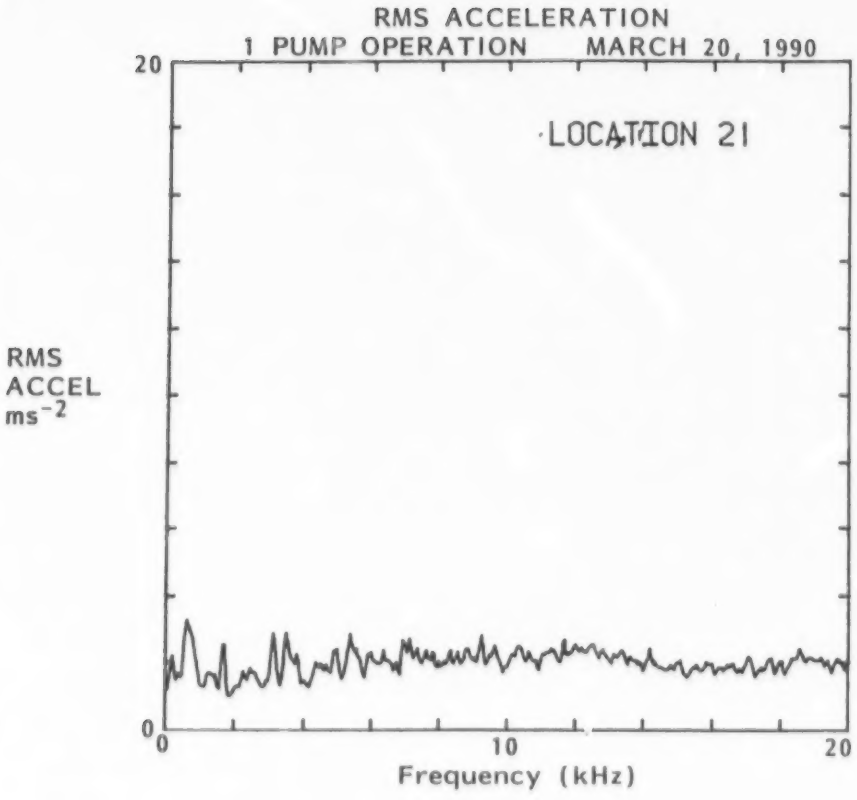


FIGURE 60

BNGS U4 MAINTENANCE COOLING PIPING VIBRATION

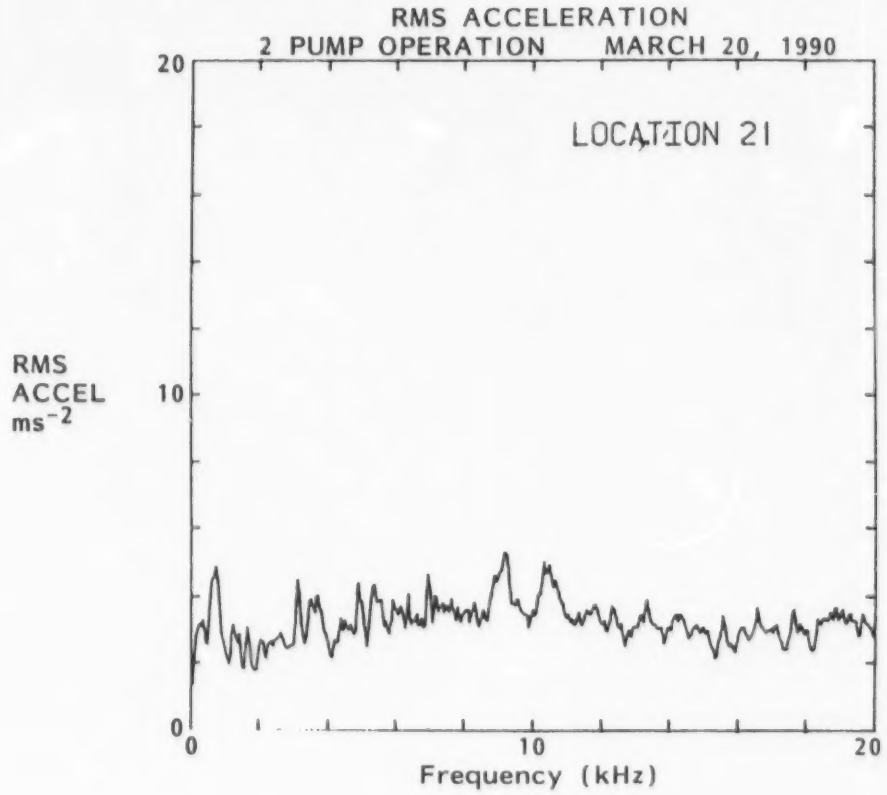


FIGURE 61

BNGS U4 MAINTENANCE COOLING PIPING VIBRATION

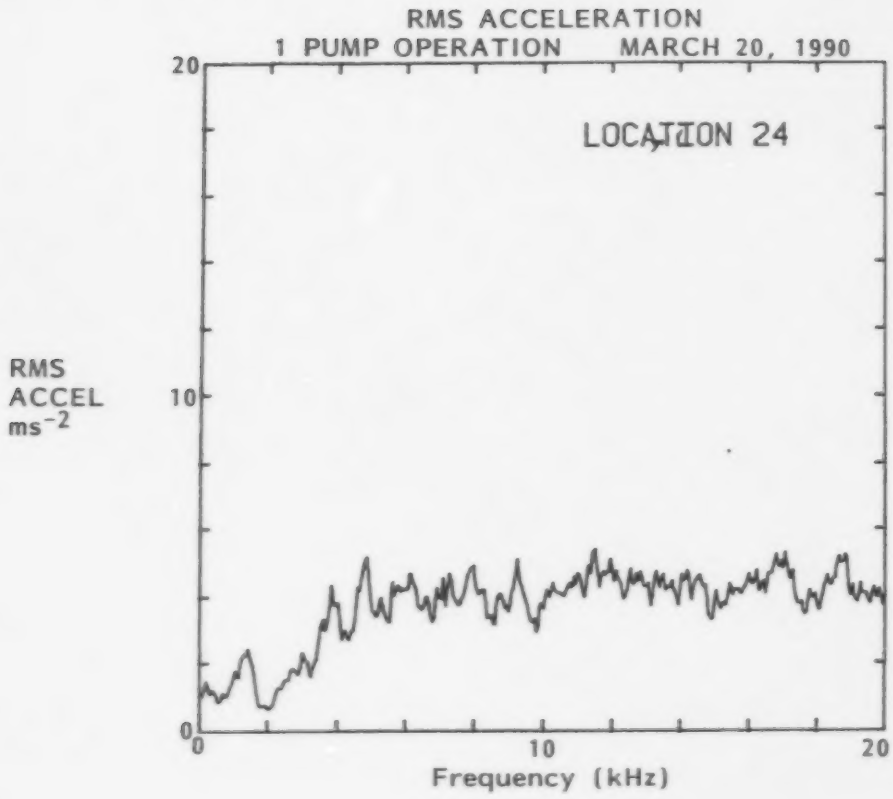


FIGURE 62

BNGS U4 MAINTENANCE COOLING PIPING VIBRATION

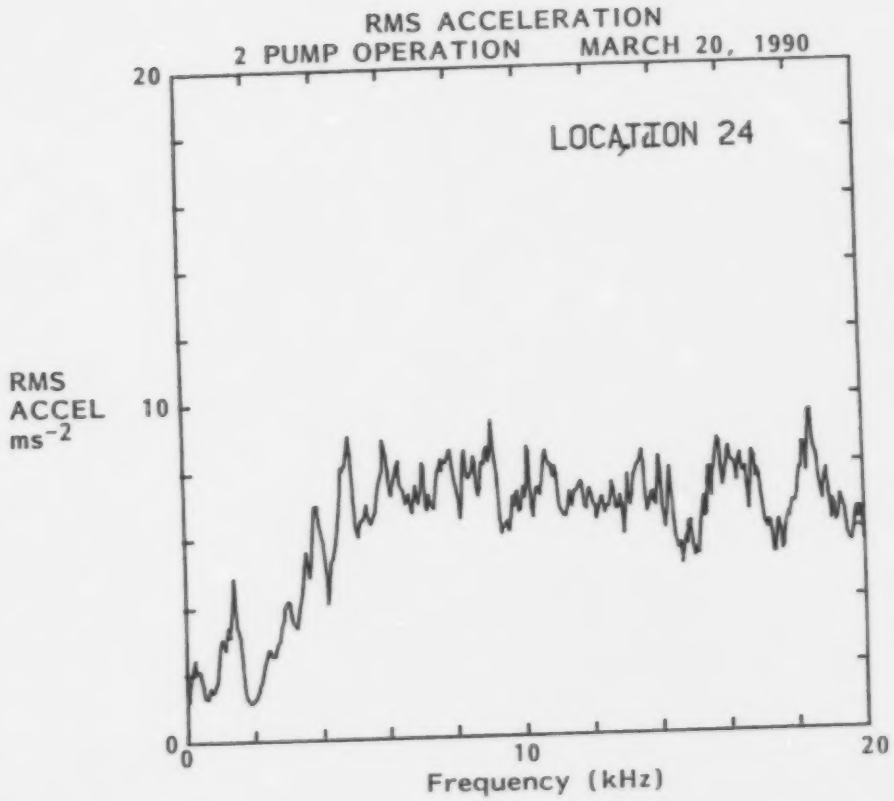


FIGURE 63

BNGS U4 MAINTENANCE COOLING PIPING VIBRATION

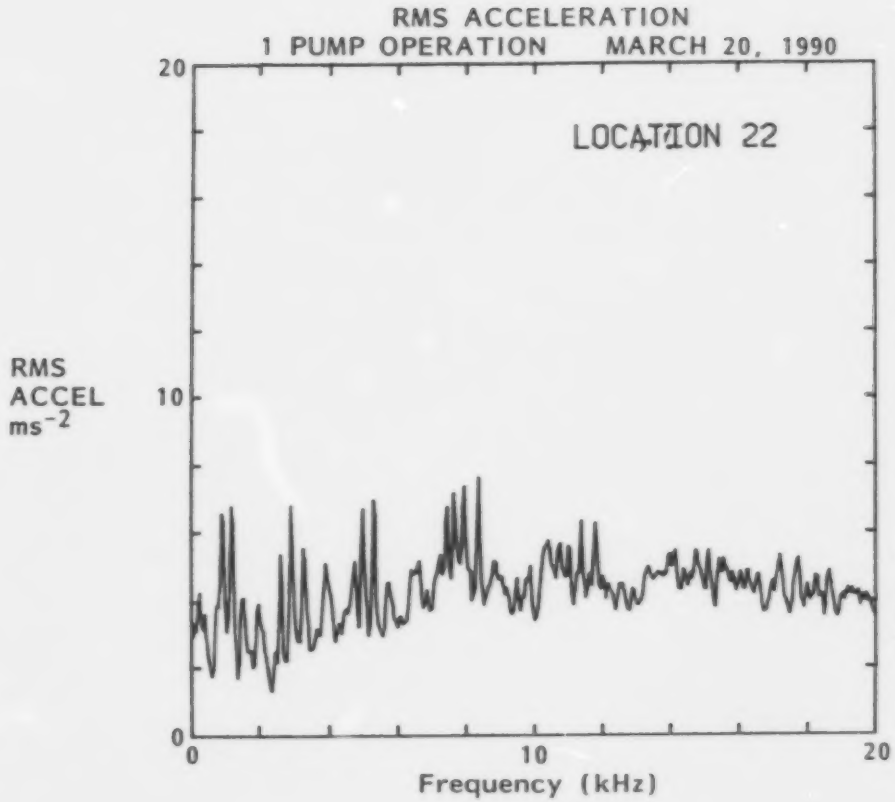


FIGURE 64

BNGS U4 MAINTENANCE COOLING PIPING VIBRATION

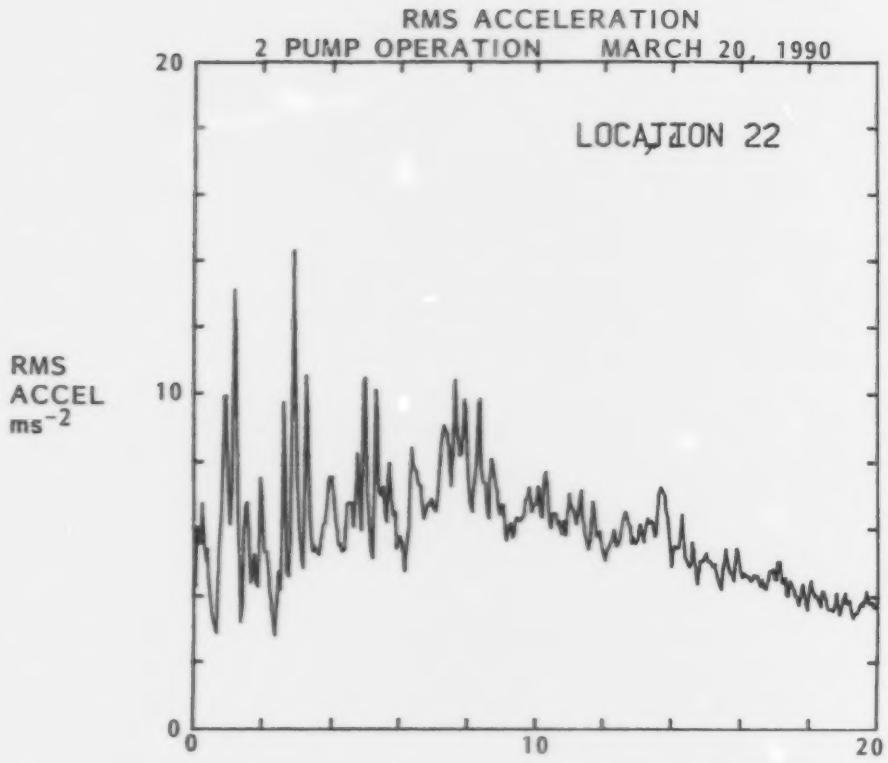


FIGURE 65

BNGS U4 MAINTENANCE COOLING PIPING VIBRATION

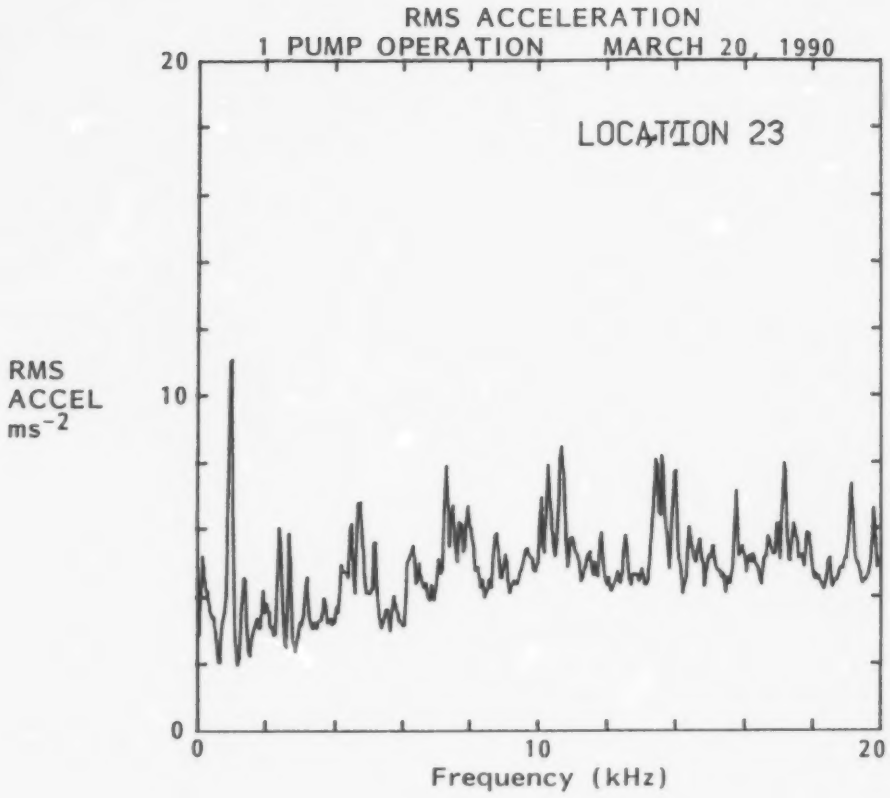


FIGURE 66

BNGS U4 MAINTENANCE COOLING PIPING VIBRATION

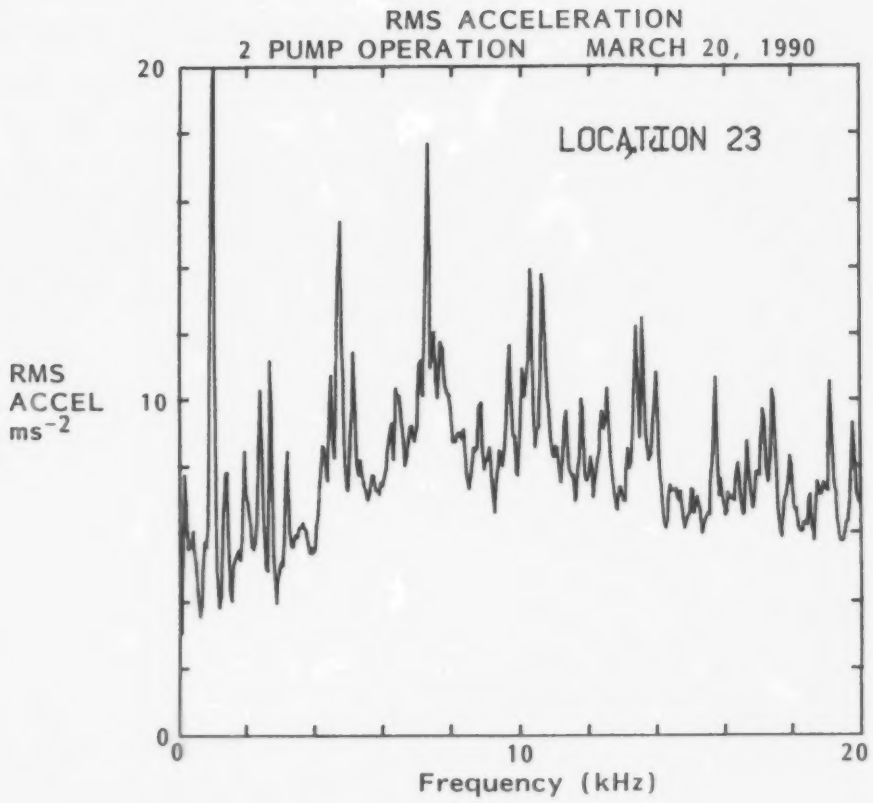


FIGURE 67

BNGS U4 MAINTENANCE COOLING PIPING VIBRATION